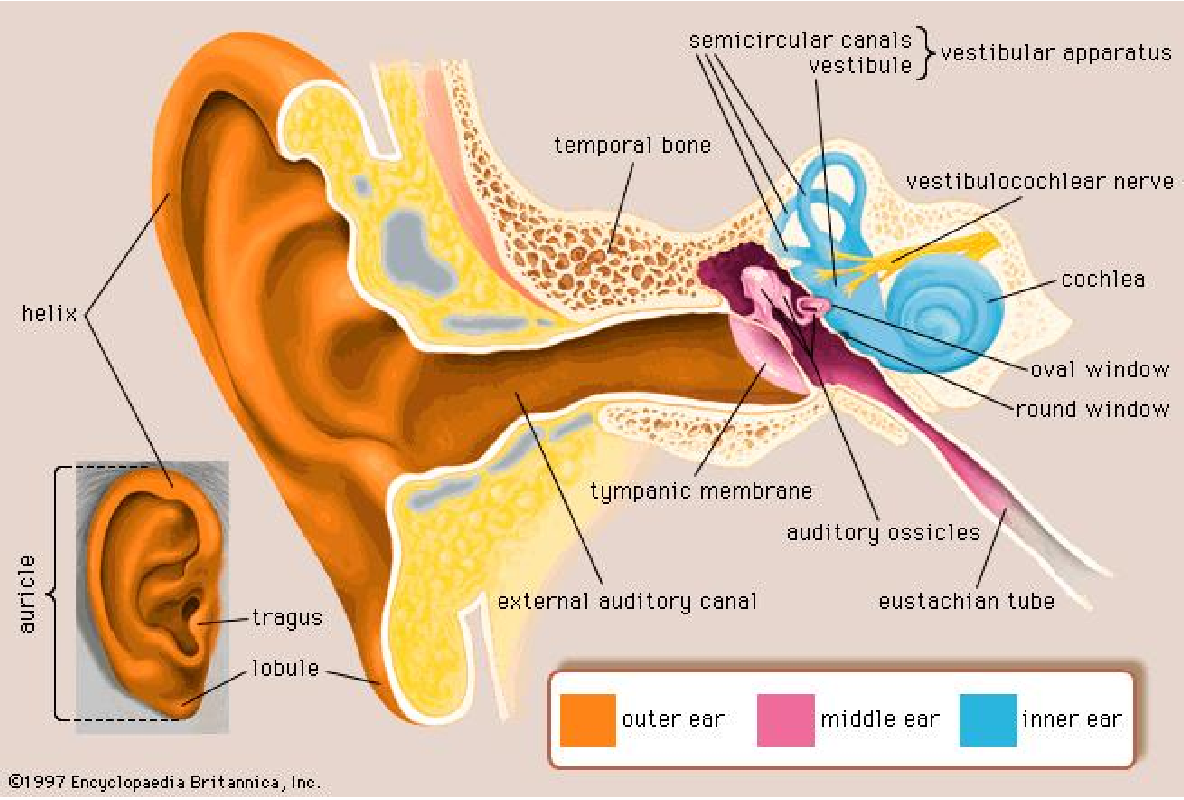
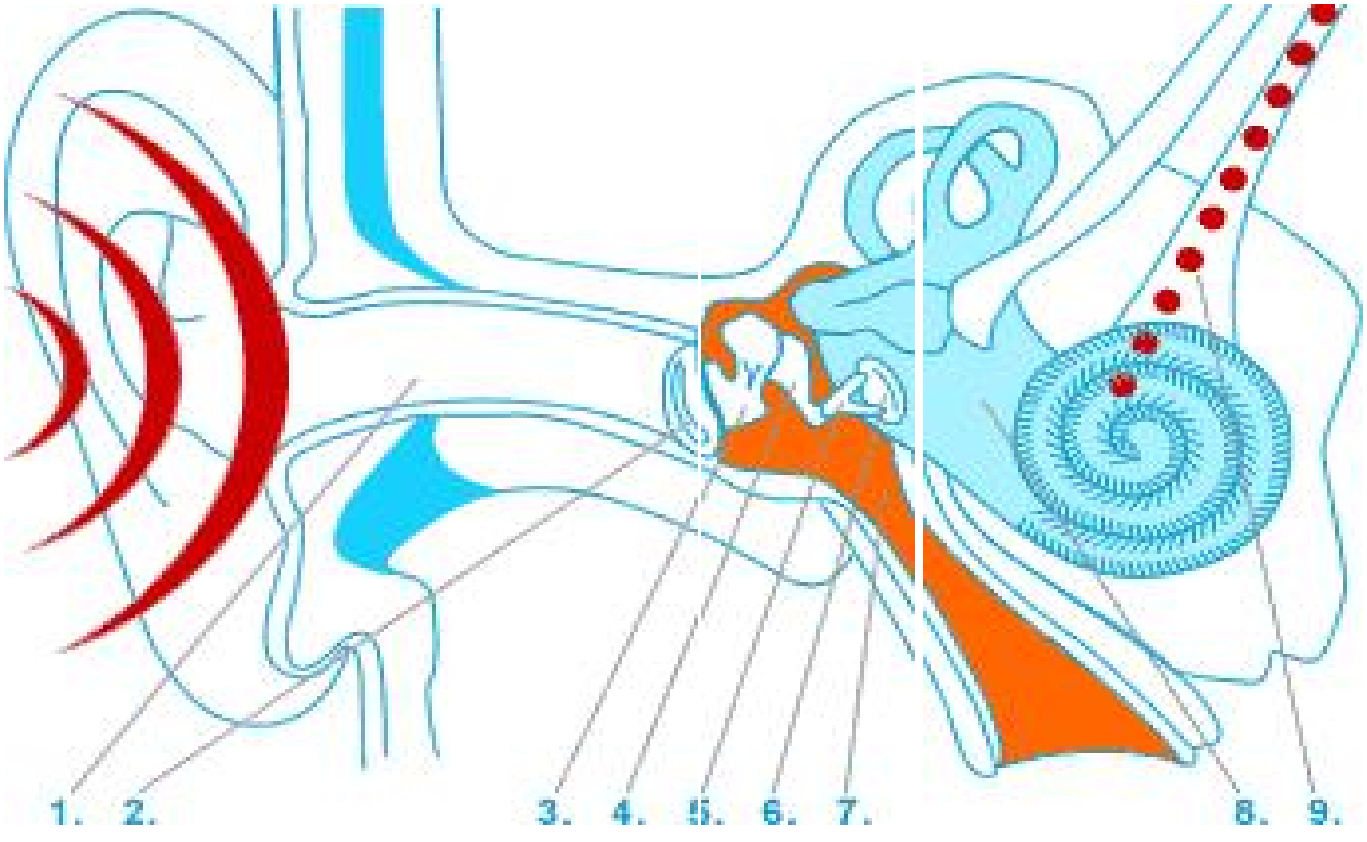
Anatomy of the Ear

- Ear has three regions
  - outer
  - middle
  - inner
- outer and middle are concerned with the transmission of sound to the inner ear
- inner ear converts sound to fluid motion and then to electrical impulses (action potentials)

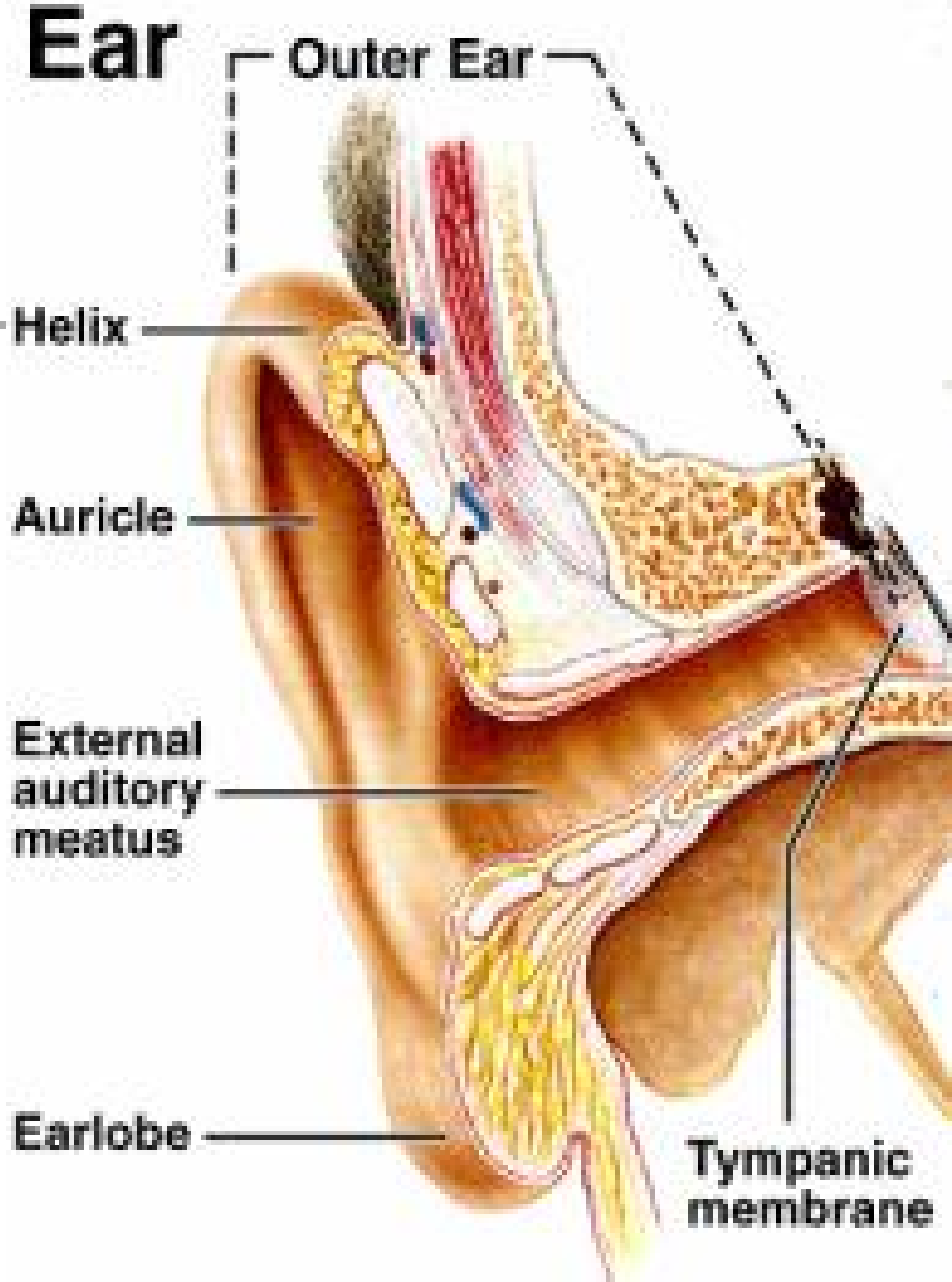


The Physiology of the Ear

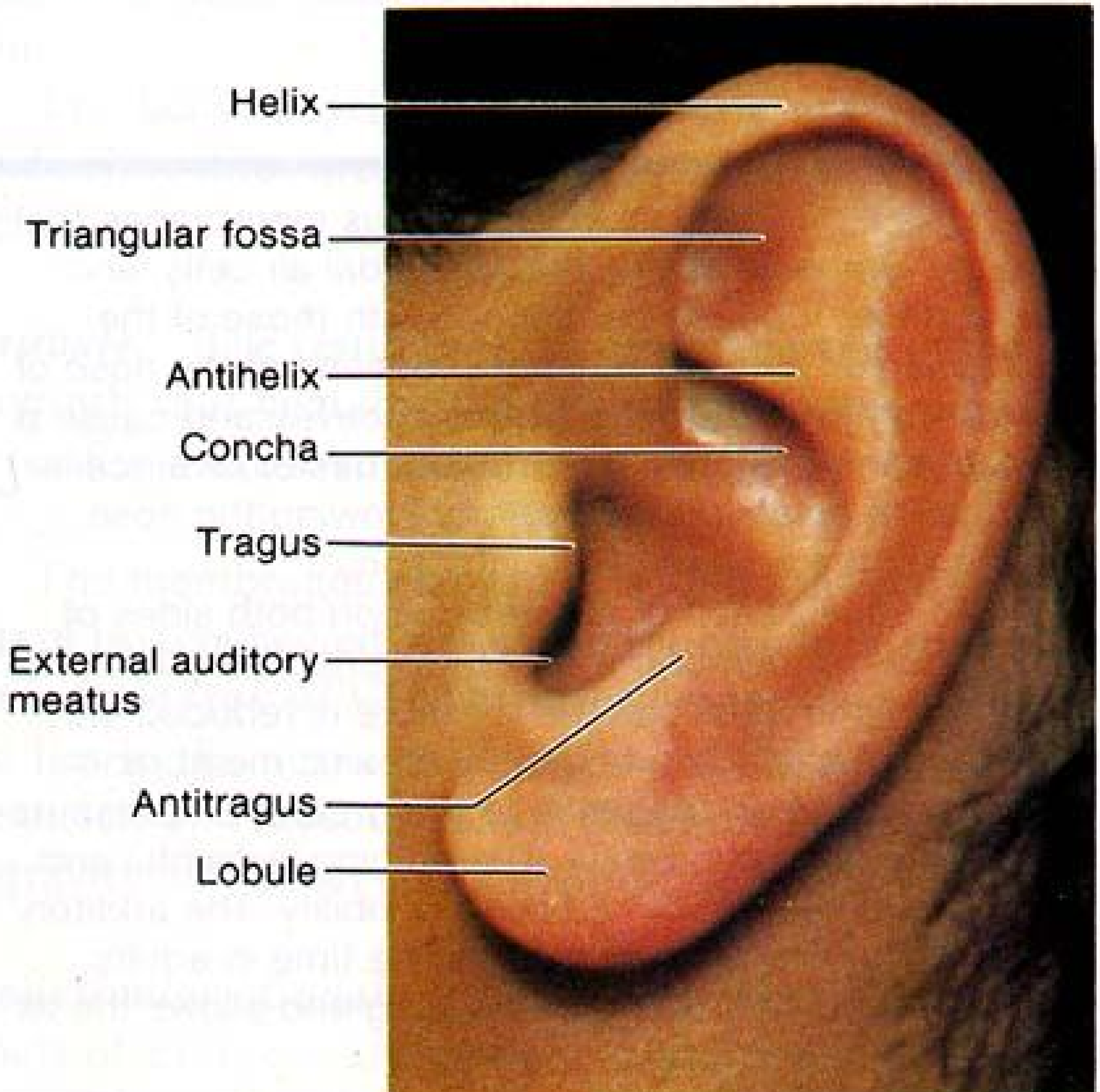


Outer Ear

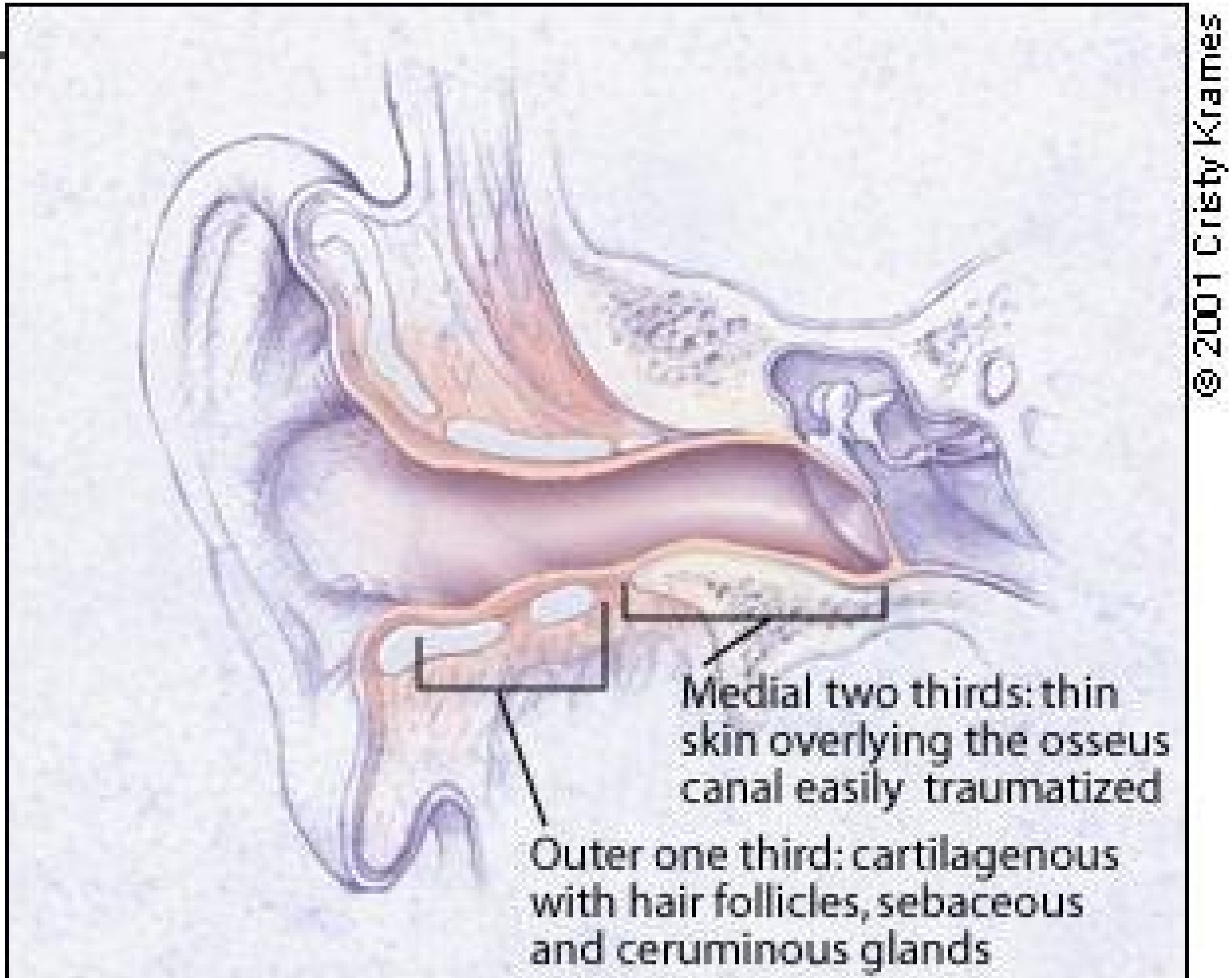
- Auricle (pinna)- flap of elastic cartilage
- External auditory canal
- Tympanic membrane (eardrum)- semitransparent thin fibroelastic connective tissue membrane, covered by epidermis on the external side and a simple low cuboidal mucous epithielium on the inner side

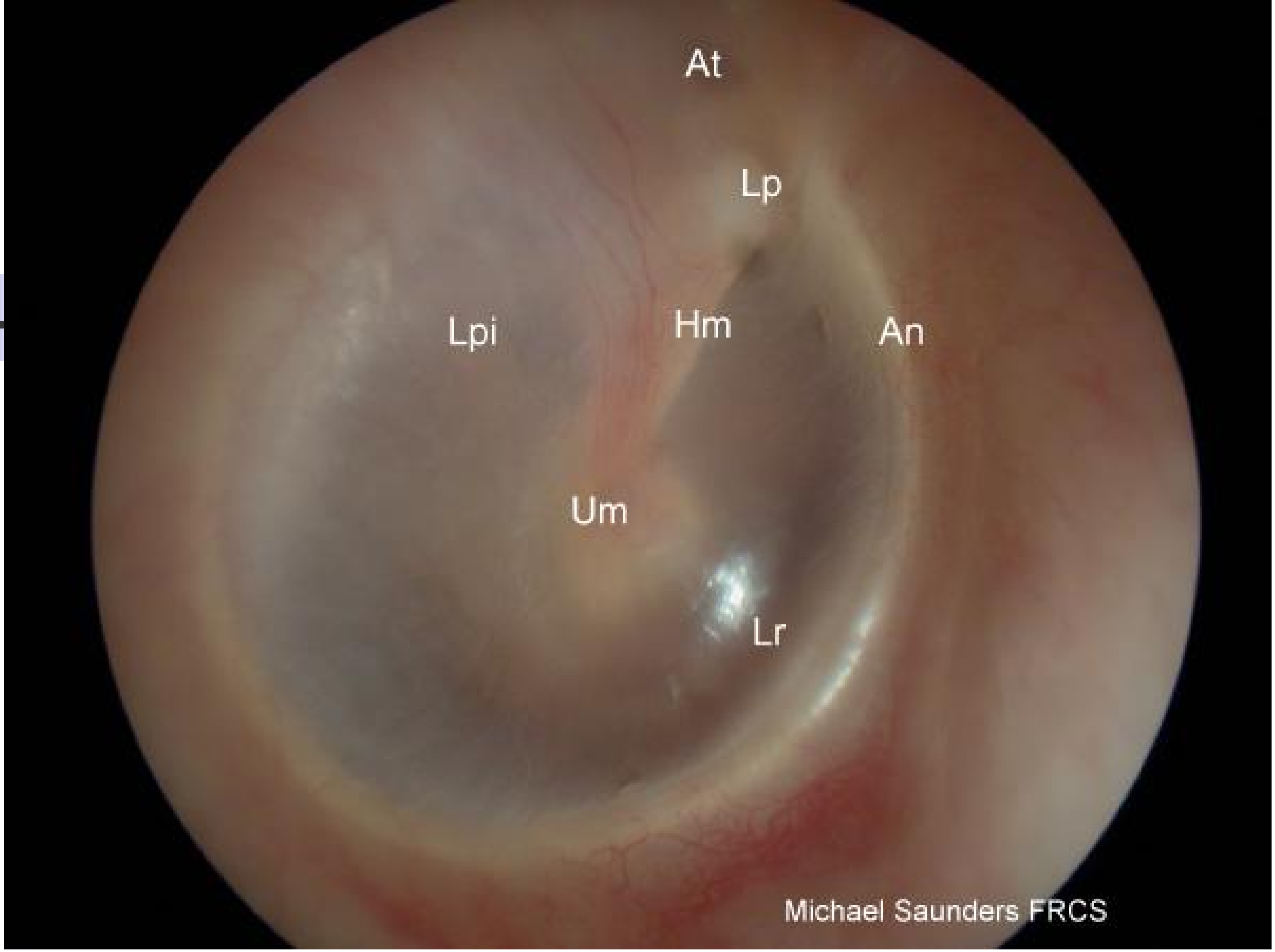


The surface anatomy of the auricle of the ear.



External Auditory Canal

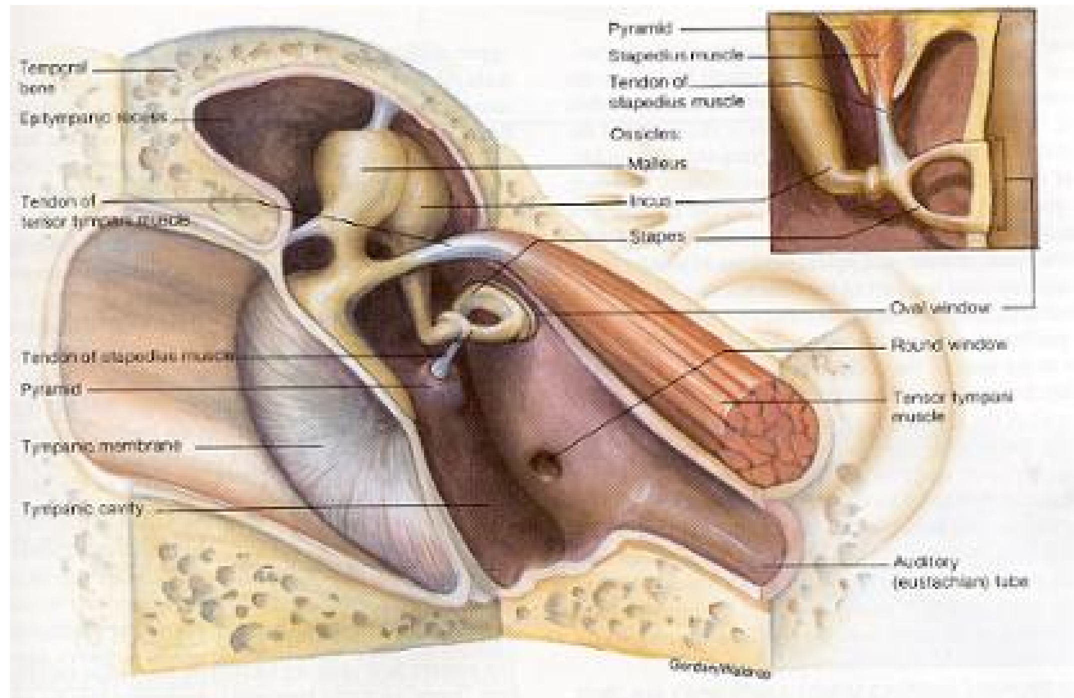




An *annulus fibrosus*
Lpi *long process of incus* - sometimes visible through a healthy translucent drum
Um *umbo* - the end of the malleus handle and the centre of the drum
Lr *light reflex* - antero-inferioirly
Lp *Lateral process of the malleus*
At *Attic* also known as *pars flaccida*
Hm *handle of the malleus*

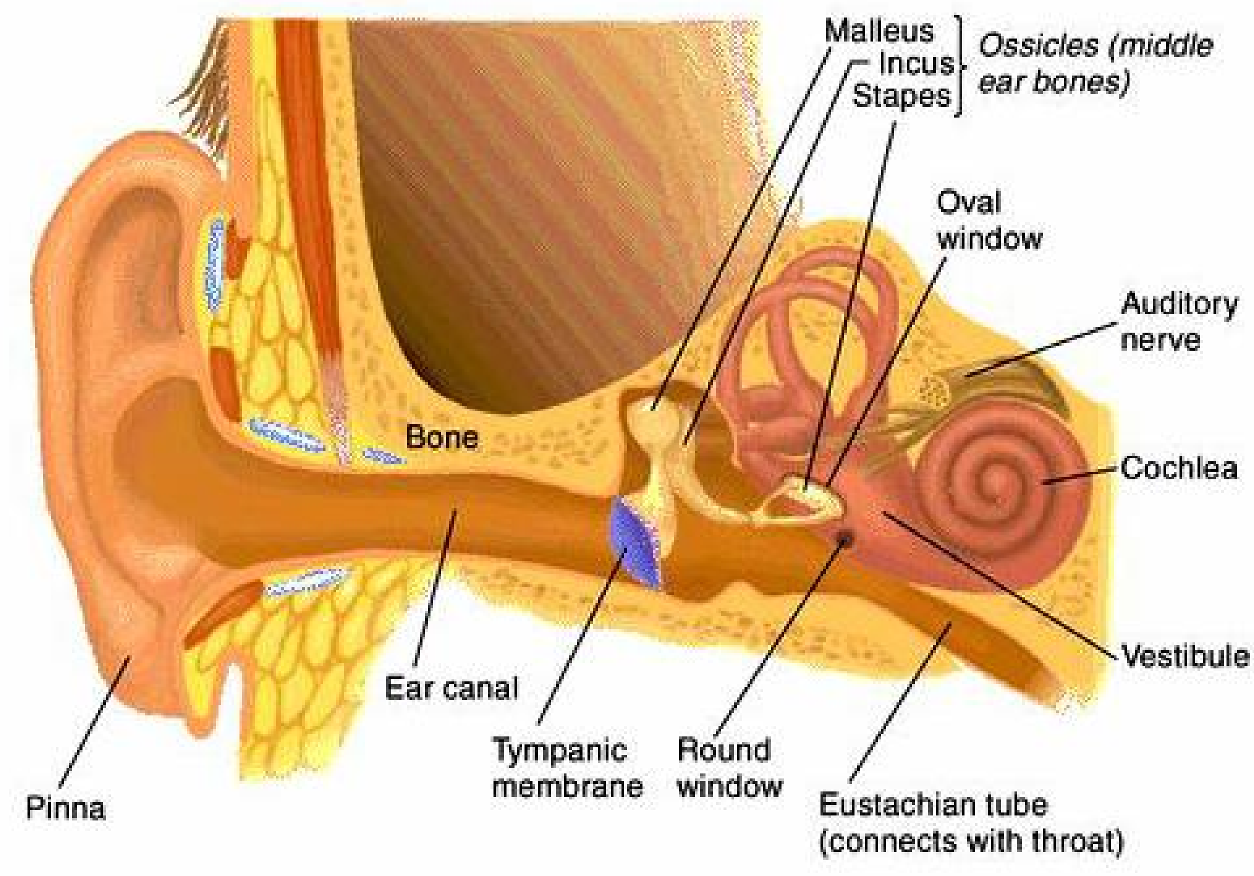
Middle Ear

- **Ossicle**s (malleus, incus, stapes)
- Oval window
- Round window
- Opening into the Eustachian tube



Inner Ear

- **Vestibular apparatus** for balance and equilibrium
- **Cochlea** for hearing



Sound

- Results from the motion of air molecules which oscillate.
- Compression and rarefaction with ea. pressure pulse --> pressure waves.
- Sound waves travel in all directions from their source.

Ears and Hearing

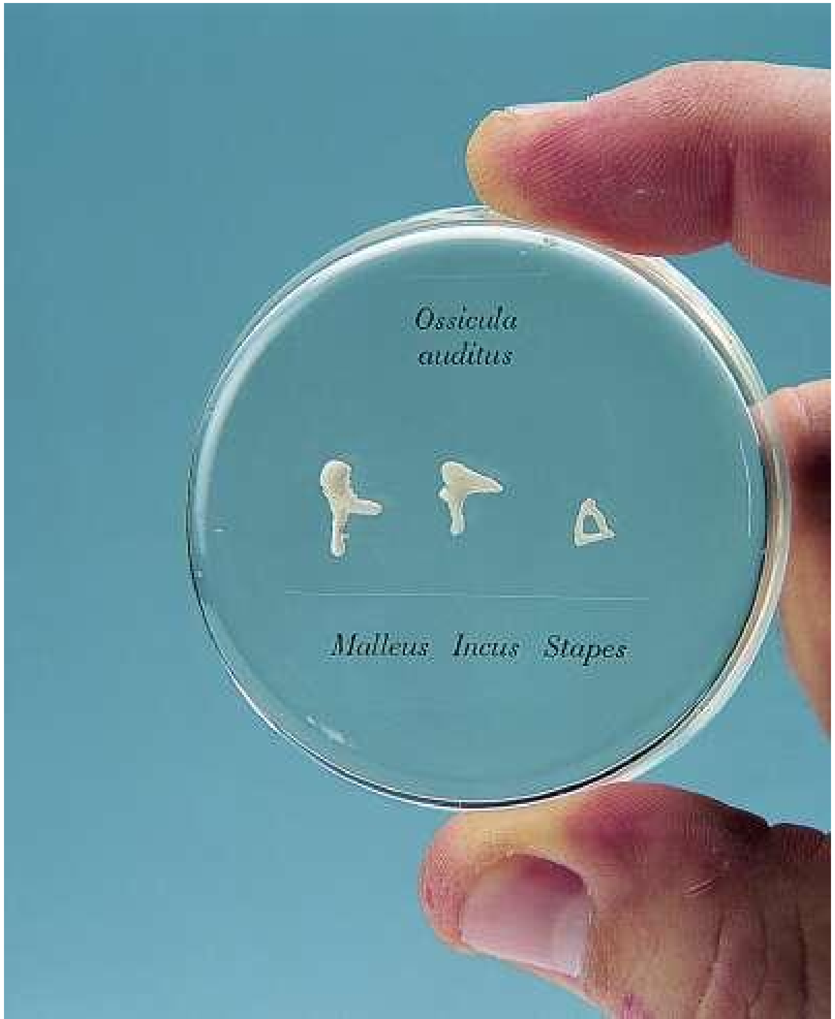
- Waves are characterized by frequency and intensity.
  - Frequency:
    - Measured in hertz (cycles per second).
    - Greater the frequency the higher the pitch.
  - Intensity:
    - Directly related to amplitude of sound waves.
    - Measured in decibels.

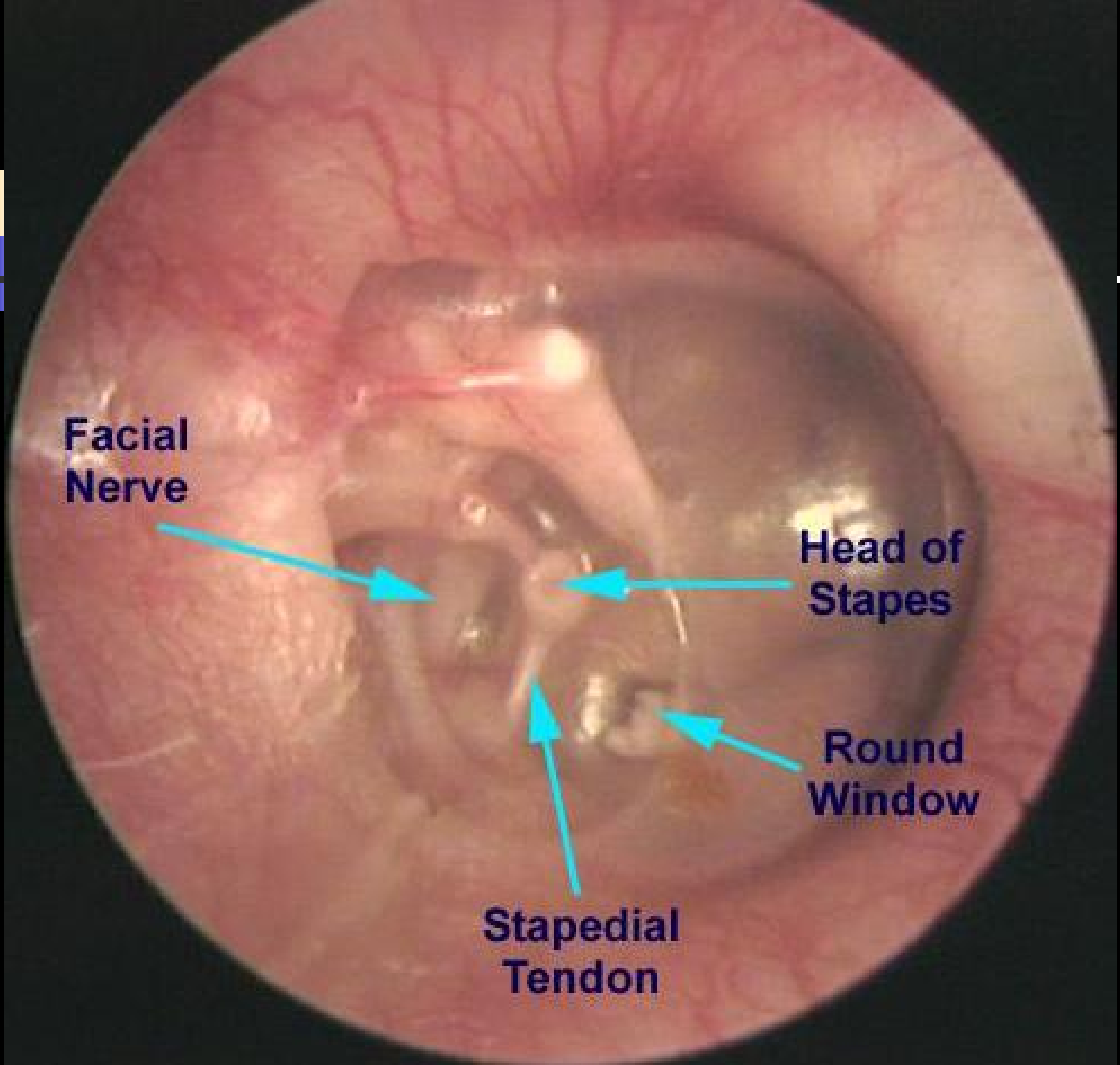
Outer Ear

- The shape of the outer ear (auricle) increases the intensity of the intermediate frequencies: those that are most important for preception of speech sounds
- Sound waves are funneled by the auricle into the external auditory meatus.
- External auditory meatus channels sound waves to the tympanic membrane.
  - Increases sound wave intensity.

Middle Ear Bones

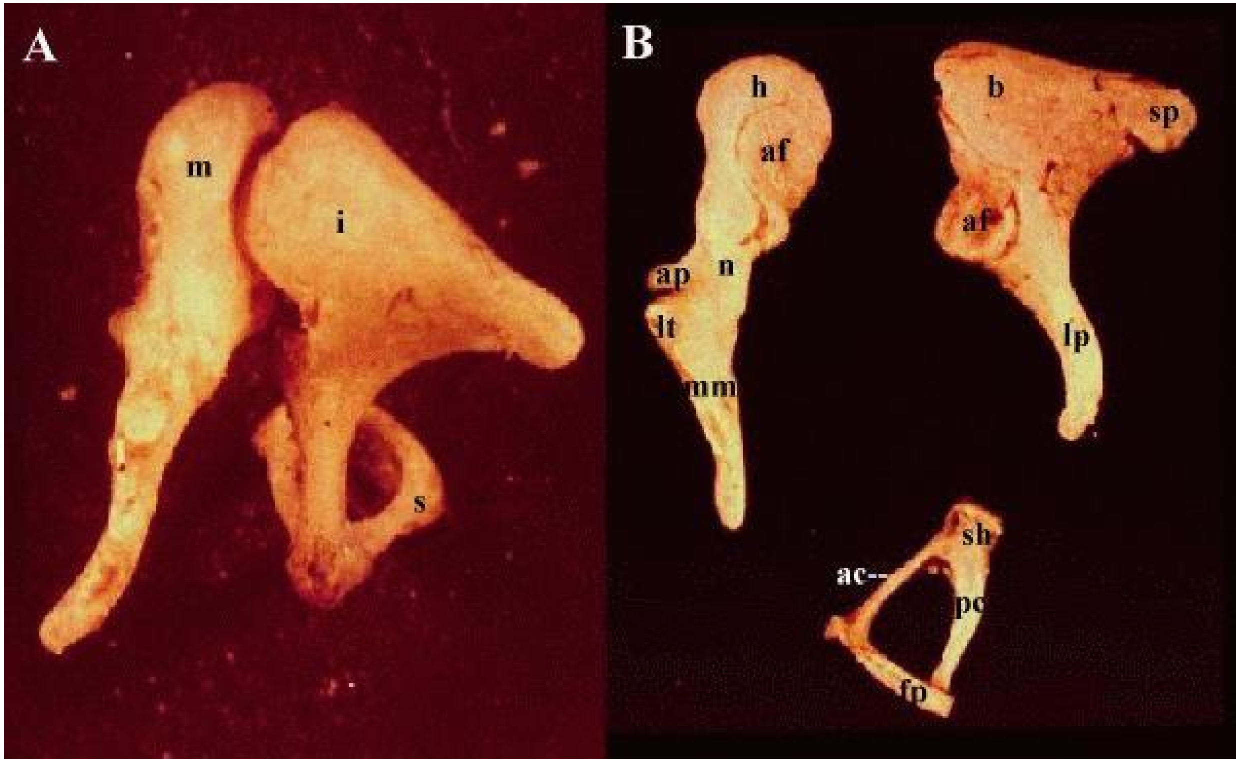
- The **ossicles** (the smallest bones in the body) amplify the sound 20 X due to leverage
  - advantage: sensitivity to soft sounds
  - -disadvantage; possible damage to sensory cells from loud sounds

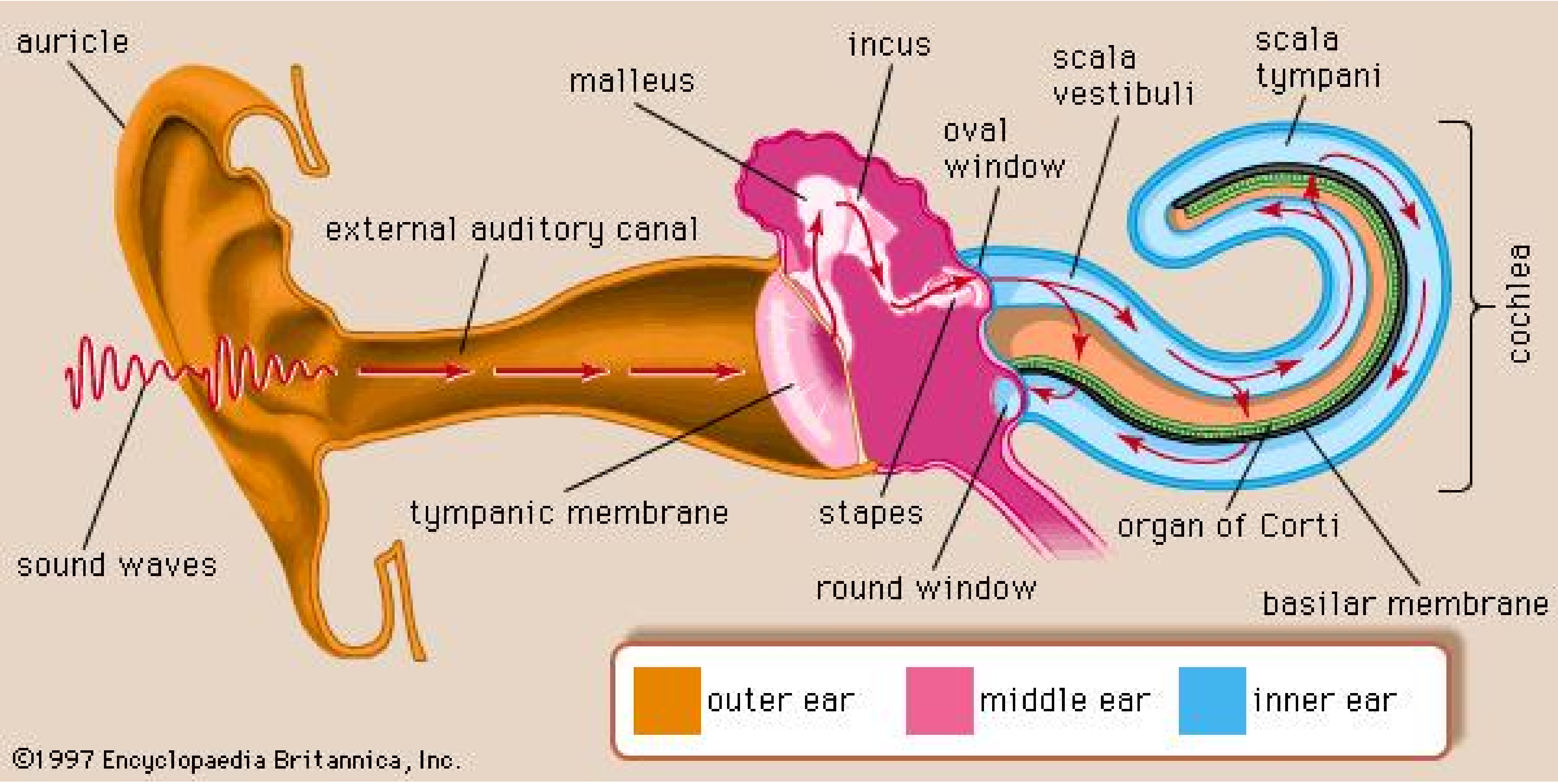



Facial
Nerve
Head of
Stapes
Round
Window
Stapedial
Tendon

Middle Ear (Cavity between tympanic membrane and cochlea)

- **Malleus**
  - Attached to tympanic membrane.
    - Vibrations of membrane are transmitted to the stapes.
- **Incus**:
    - Anvil.
- **Stapes**:
    - Attached to oval window.
    - Vibrates in response to vibrations in tympanic membrane.



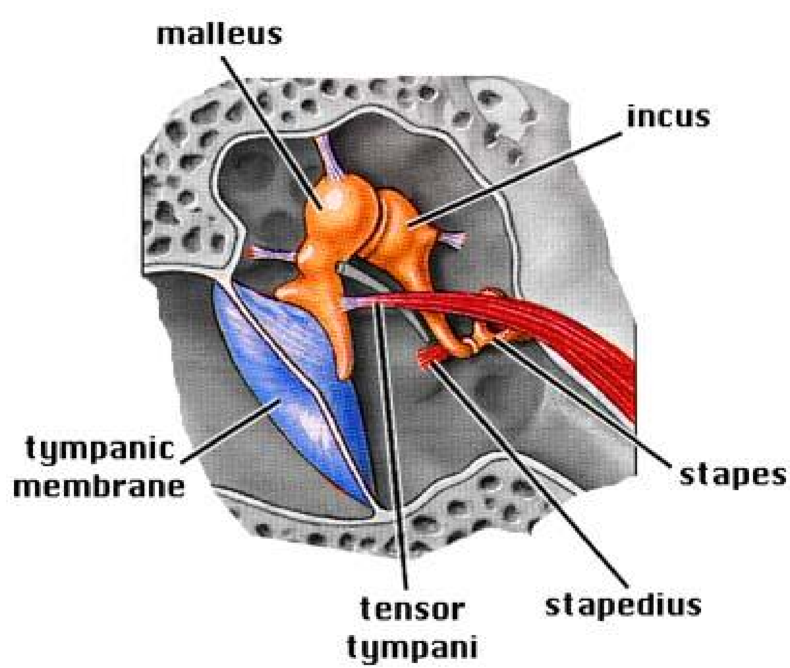


Ossicles transmit sound form an air medium to a fluid medium

Muscles of the Middle Ear

- **Stapedius**
  - the **smallest skeletal muscle** in the human body.
  - **connects to the stapes** (the stirrup)
  - when it contracts, **it reduces the action of the stapes** (i.e., it reduces amplification)
  - **contracts just before speaking and chewing** because our own speaking and chewing actually could be loud enough to damage the sensitive mechanisms of the inner ear if the sounds were further amplified.
  - innervated by a branch of the Facial Nerve (CN VII).

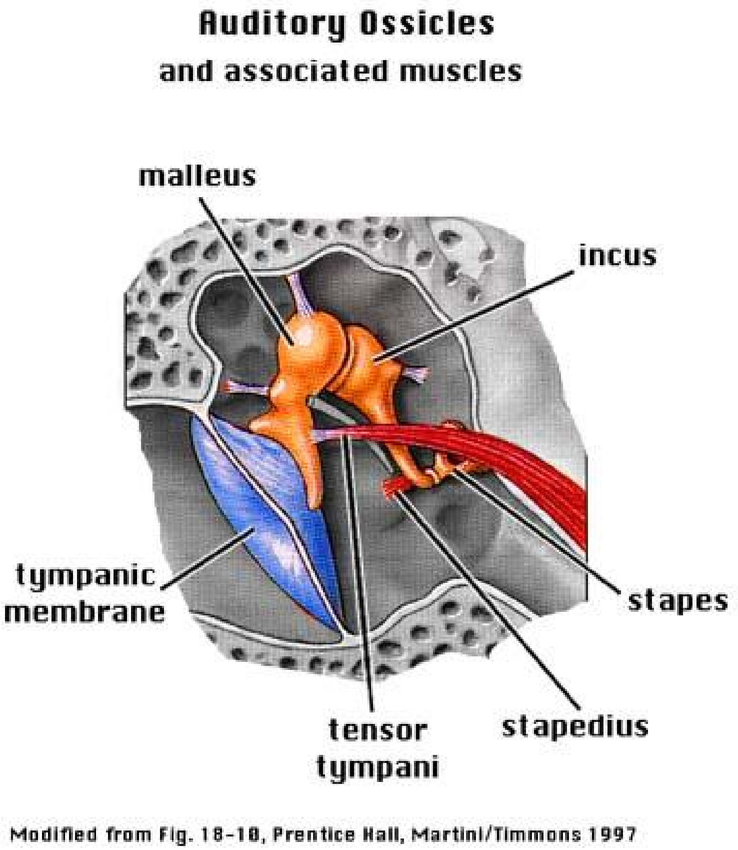
Auditory Ossicles
and associated muscles



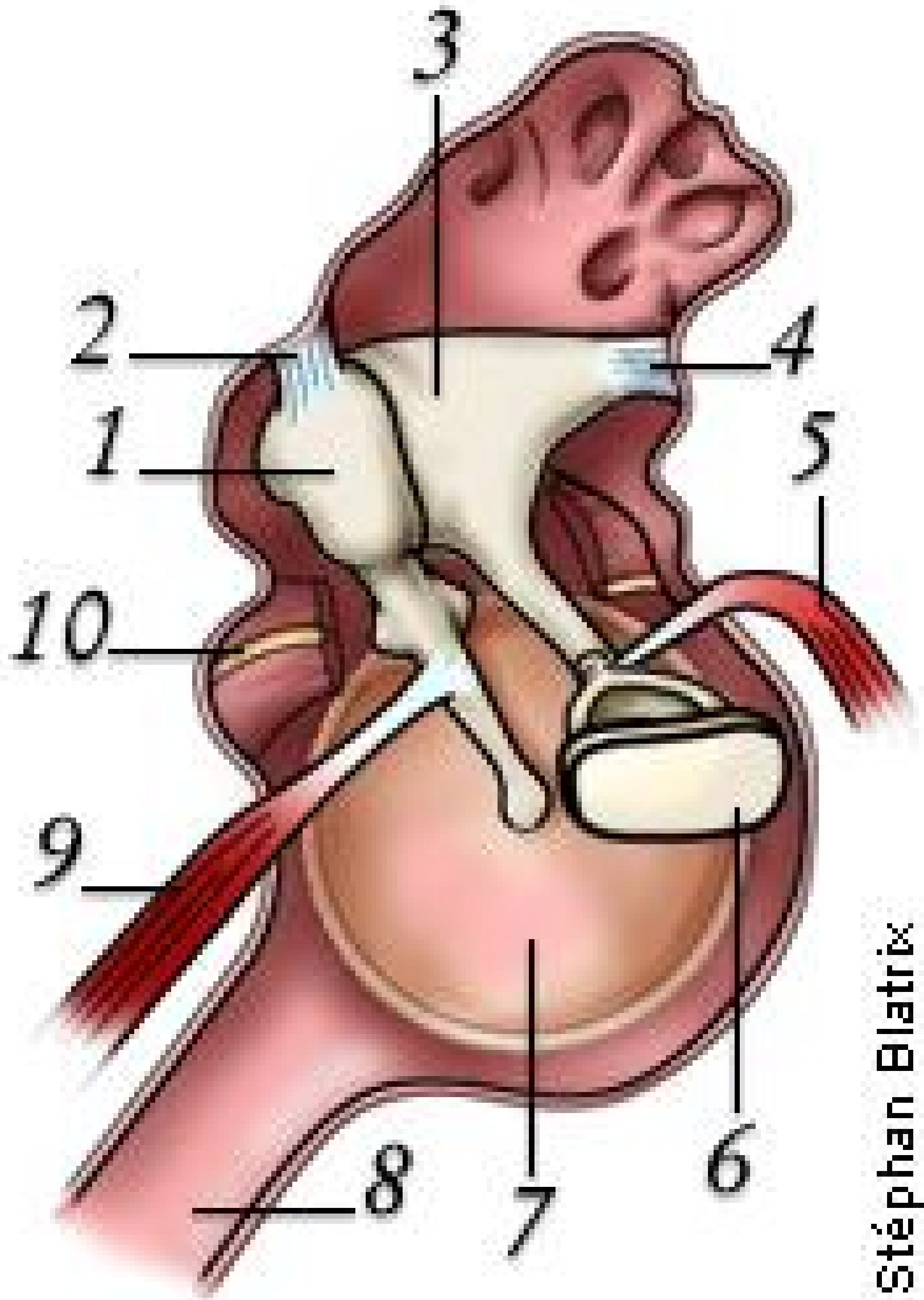
Modified from Fig. 18-10, Prentice Hall, Martini/Timmons 1997

Muscles of the Middle Ear

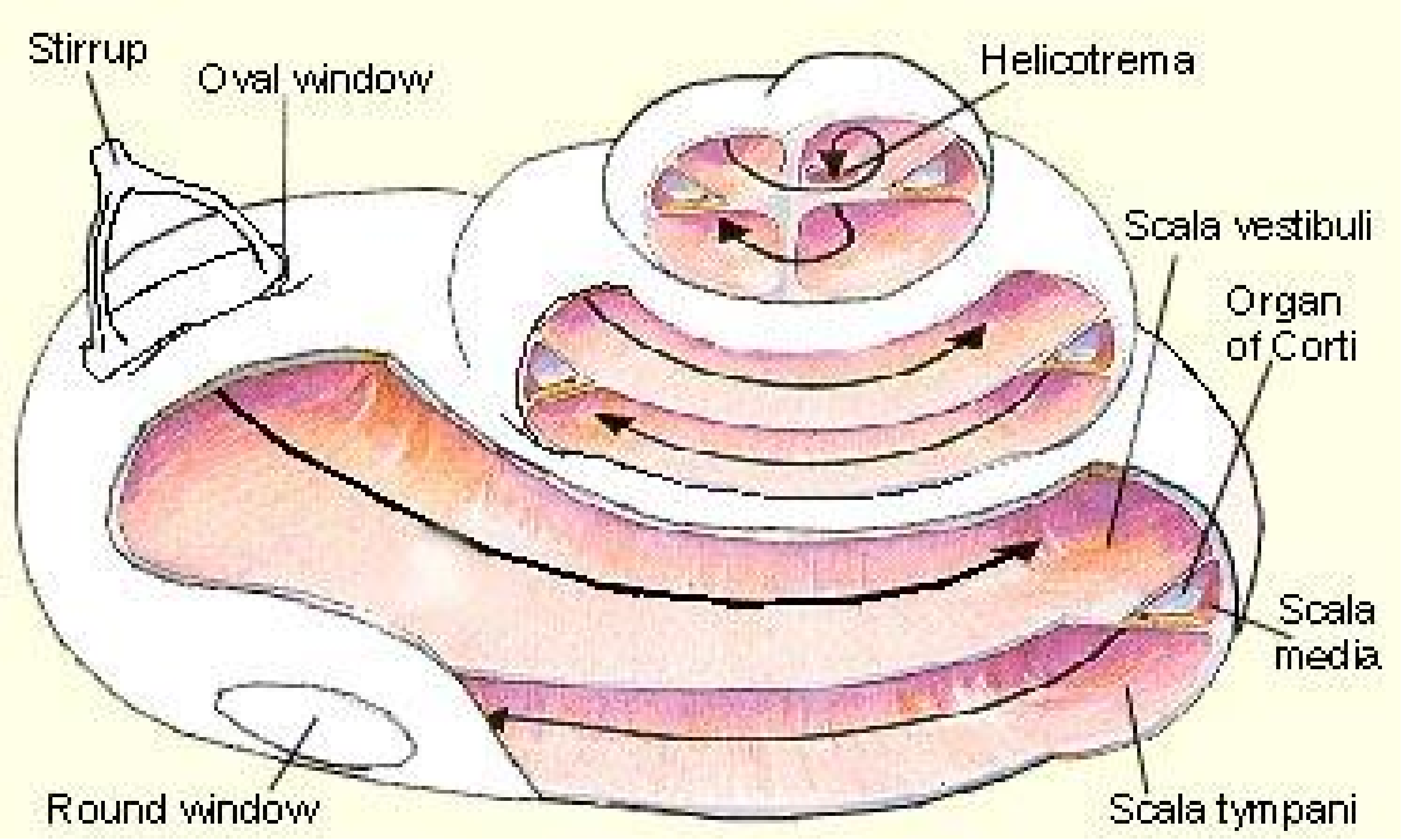
- **Tensor tympani**
  - **inserts on the malleus** and **acts to <u>tense</u> the tympanic membrane** reducing the effectiveness of sound transmission, protecting the inner ear during loud sounds.
  - innervation from a branch of the mandibular nerve (V3 of CN V).



- (1) Malleus ;
- (2) Malleus ligament ;
- (3) Incus ;
- (4) Incus ligament;
- (5) Stapes muscle (stapedius);
- (6) Stapes footplate;
- (7) Eardrum;
- (8) Eustachian tube;
- (9) Malleus muscle (tensor tympani);
- (10) Nerve (chorda tympani) sectioned.



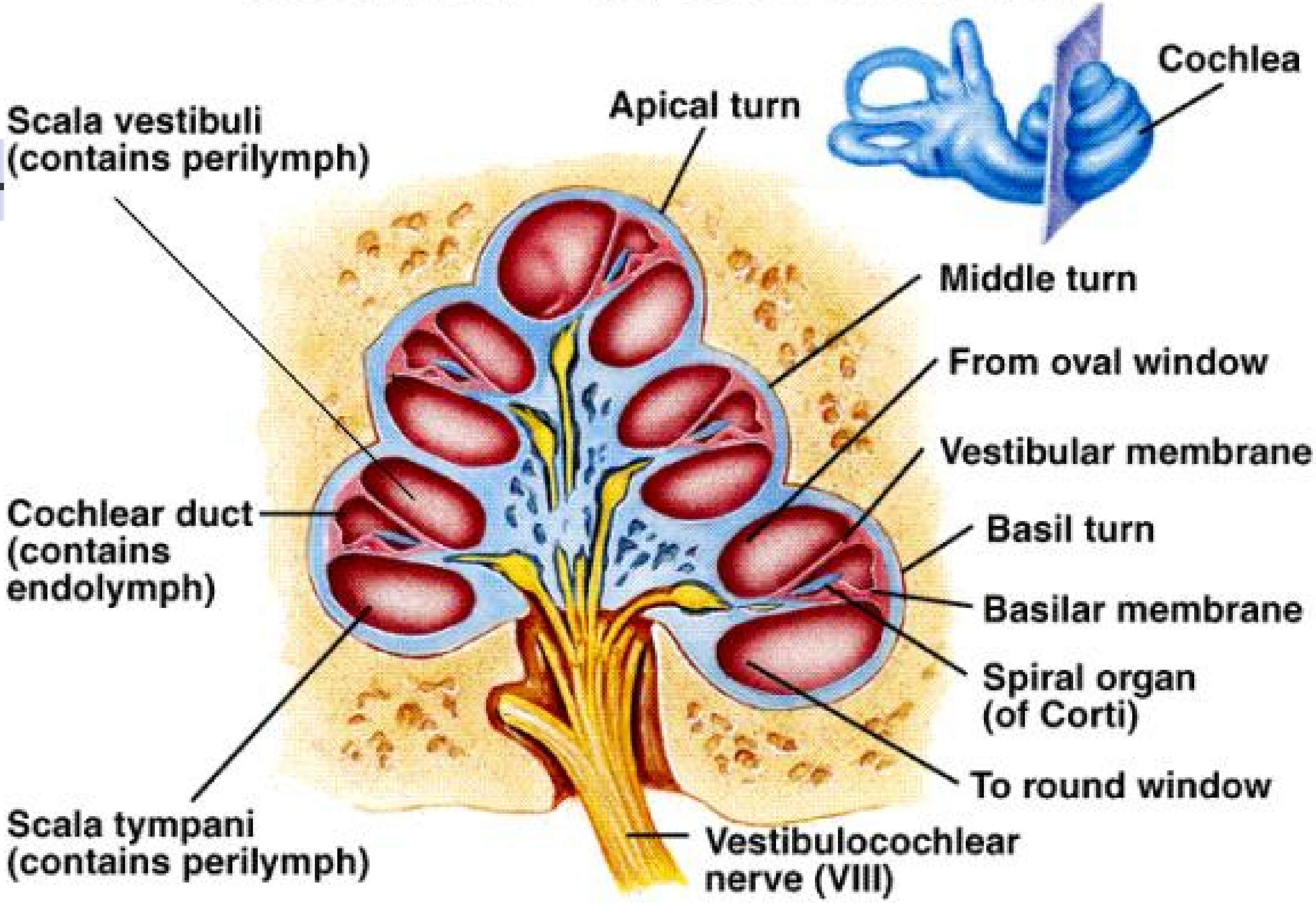
Bony Labyrinth of Cochlea

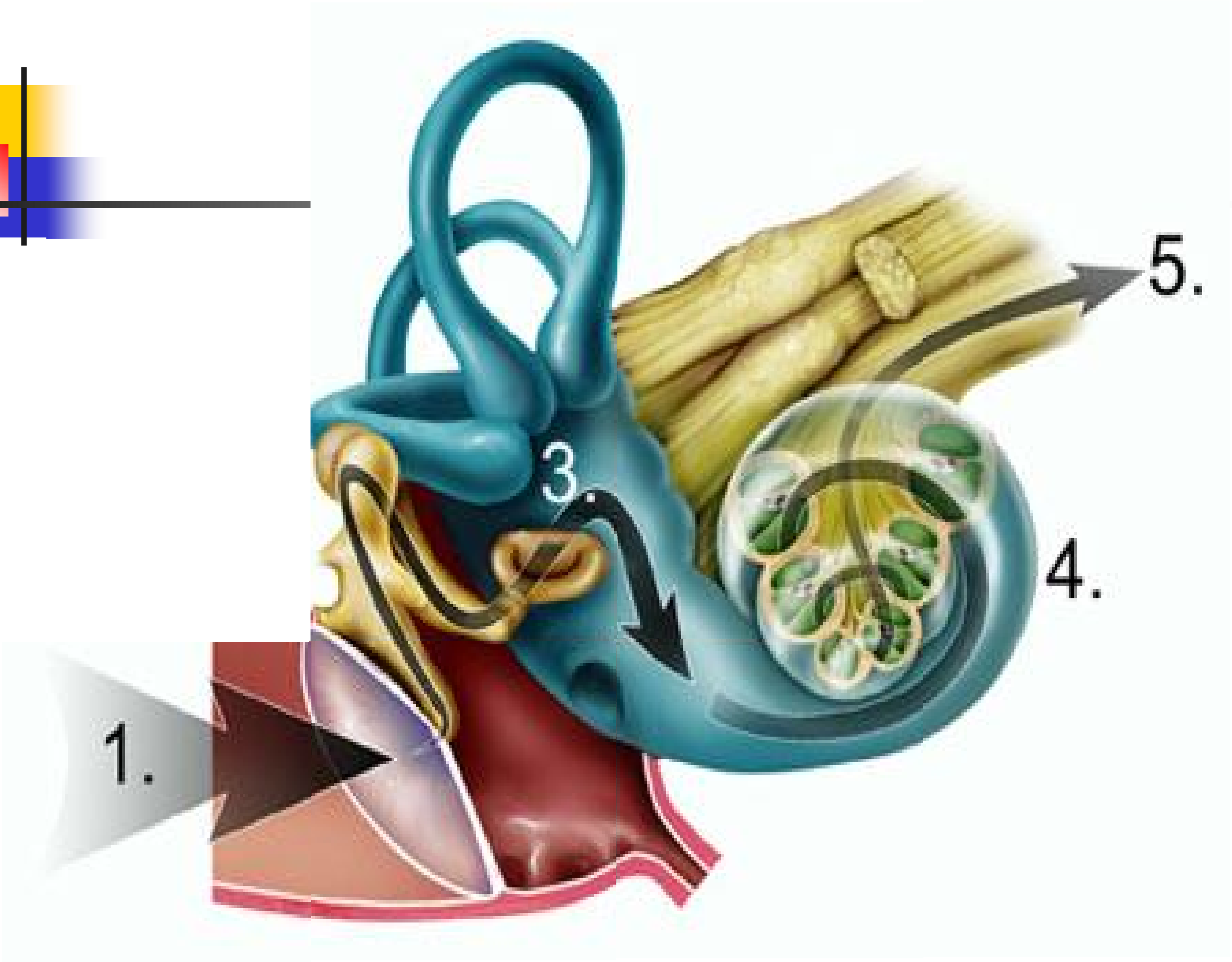


Membranous labyrinth of Cochlea

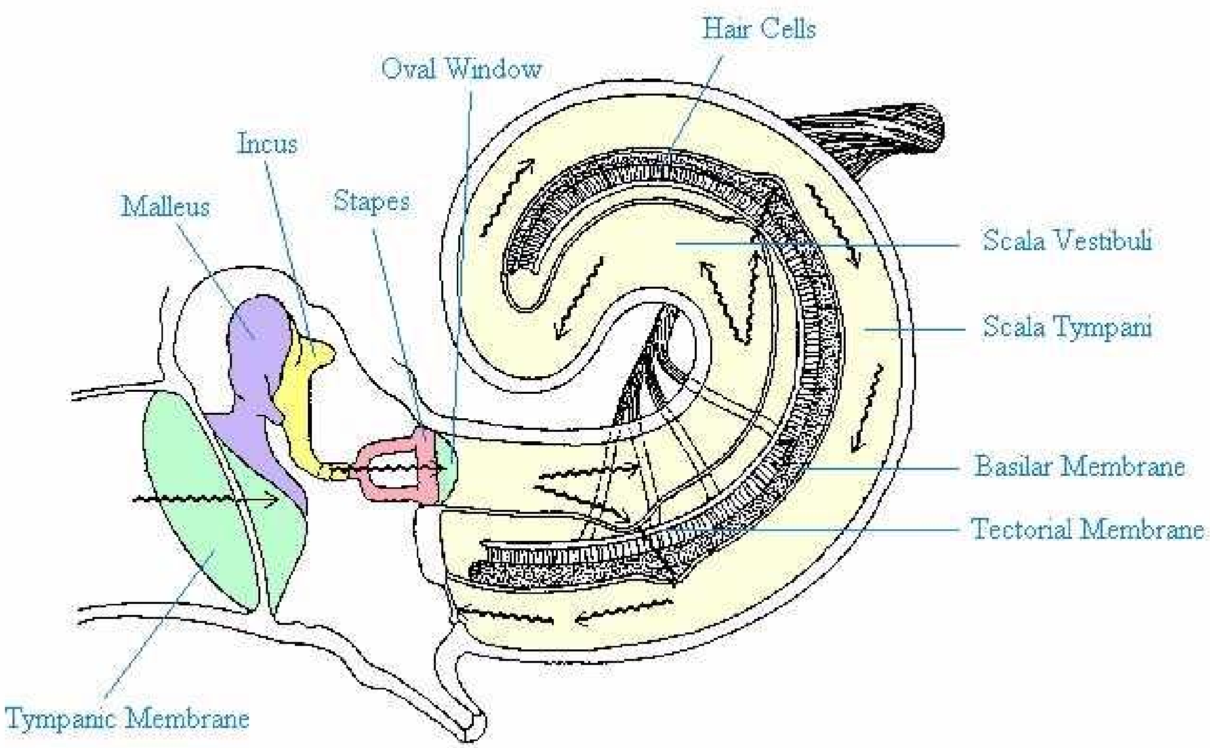
The bony capsule (bony labayrinth) has been dissected out, showing the 2 1/2 coils of the membranous labyrinth (35 mm in length). The oval (blue arrow) and round (yellow arrow) windows are indicated.

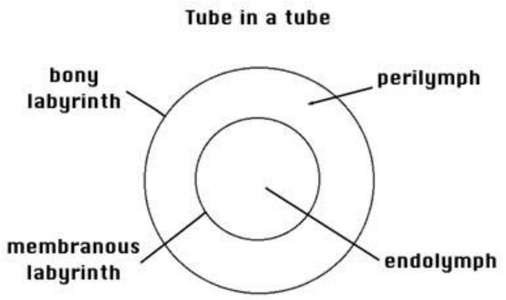
Cochlea—Cross Section

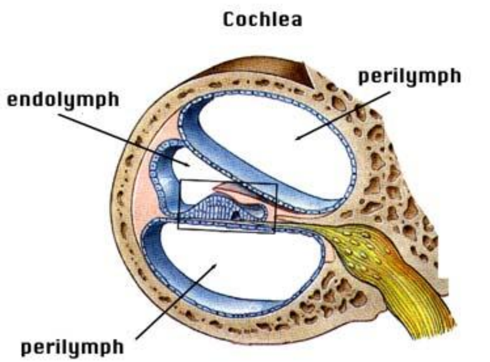



1.
3.
4.
5.

Cochlear Physiology

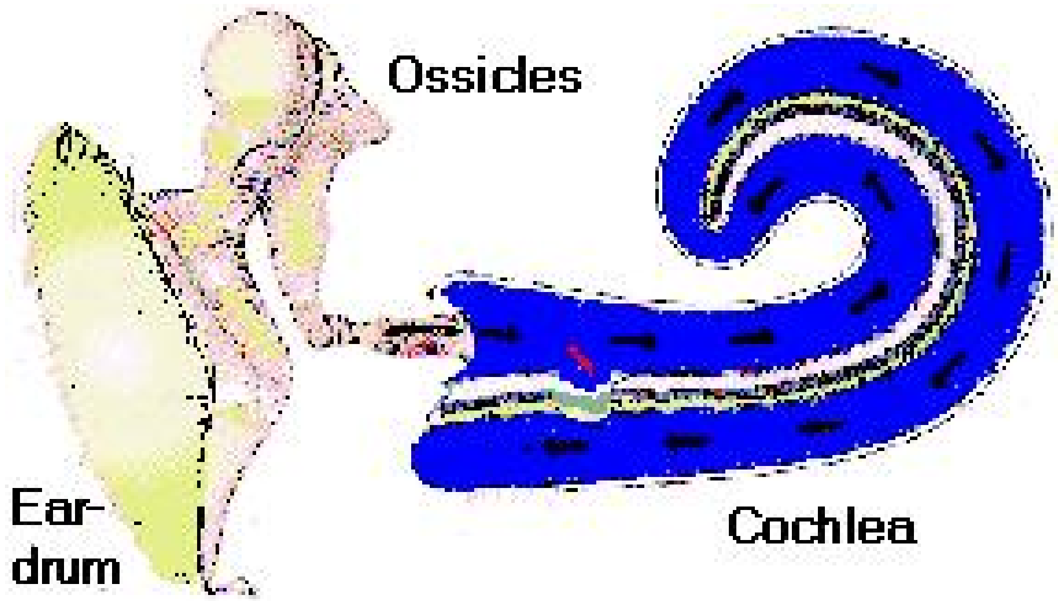






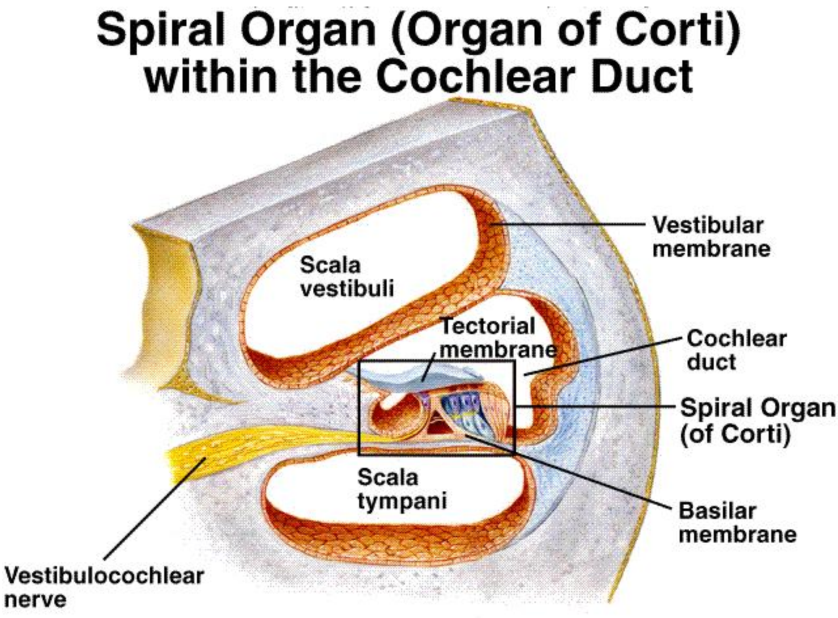
Cochlea

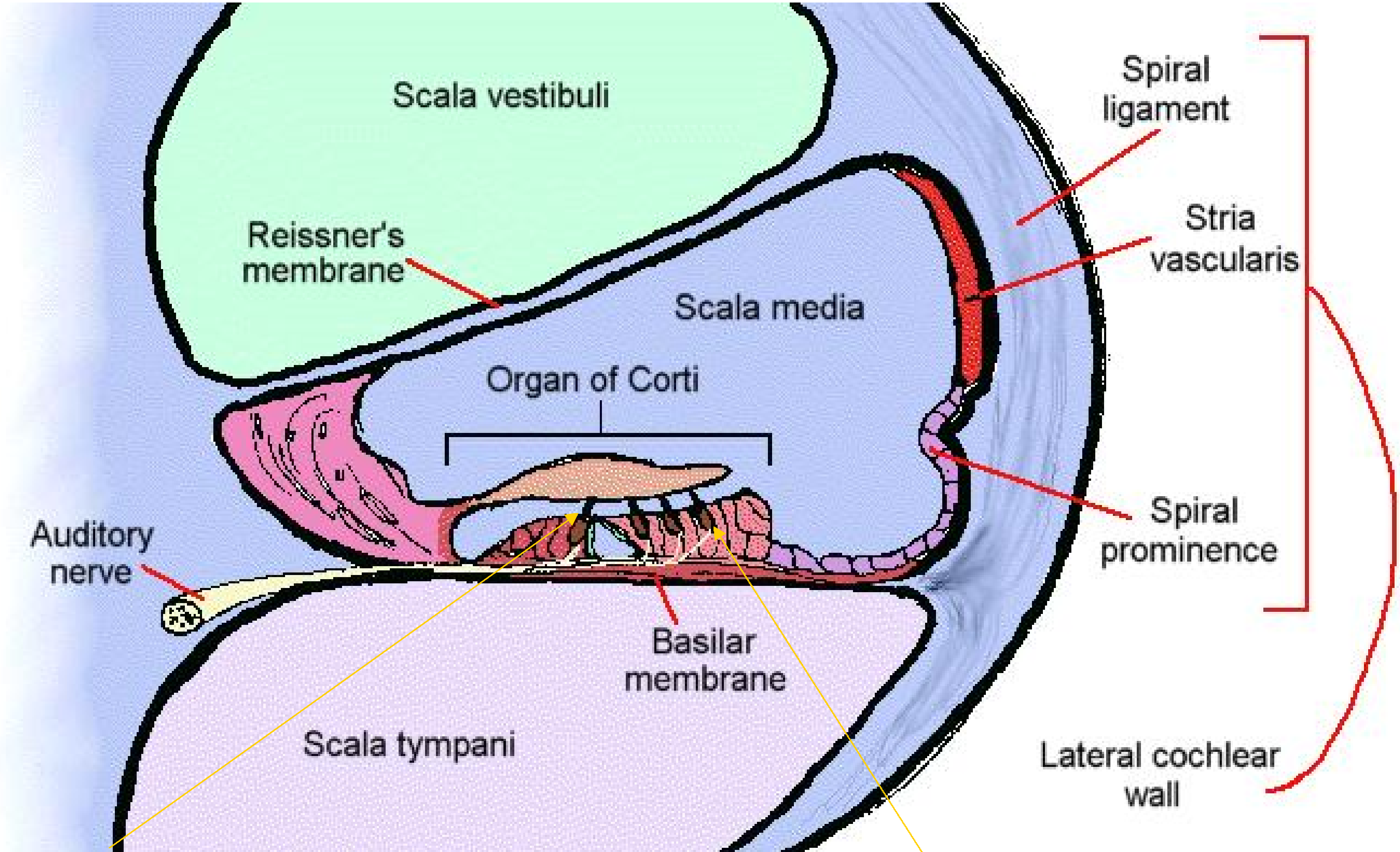
- **Vibrations of stapes and oval window displace perilymph** fluid within **scala vestibuli**.
- **Vibrations pass to the scala tympani.** As sound frequency increases, pressure waves of the perilymph are transmitted **through the vestibular membrane and through the basilar membrane.**
- **Movements of perilymph** travel to the base of cochlea where they **displace the round window.**



Organ of Corti

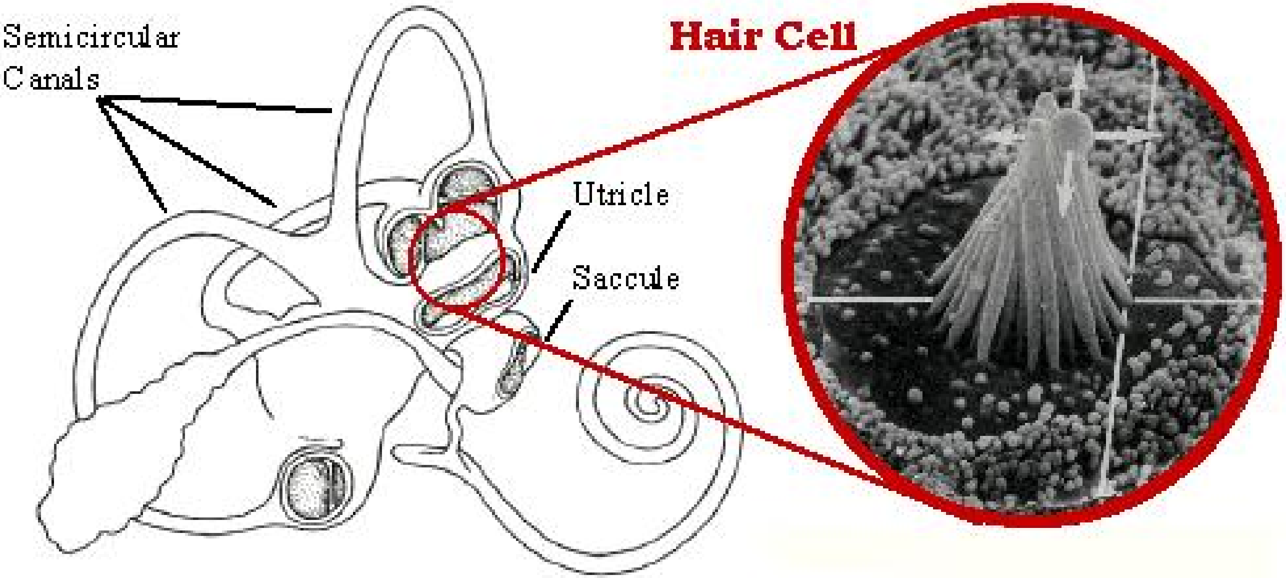
- Sensory hair cells located on the **basilar membrane.**
- **Stereocilia** of the outer hair cells are embedded in the **tectorial membrane**.

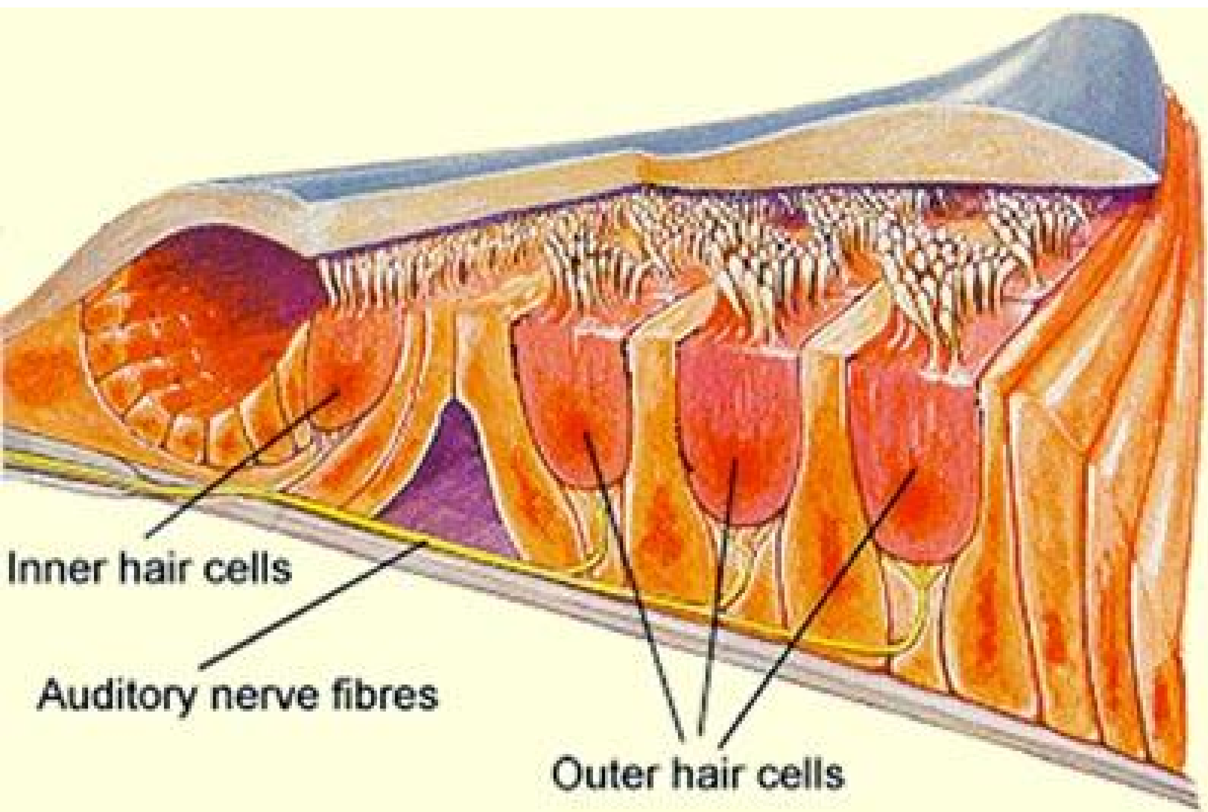


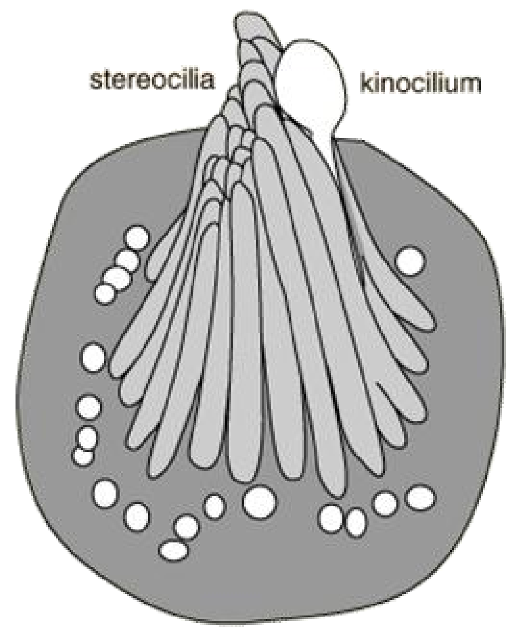


inner hair cells outer hair cells

Stereocilla

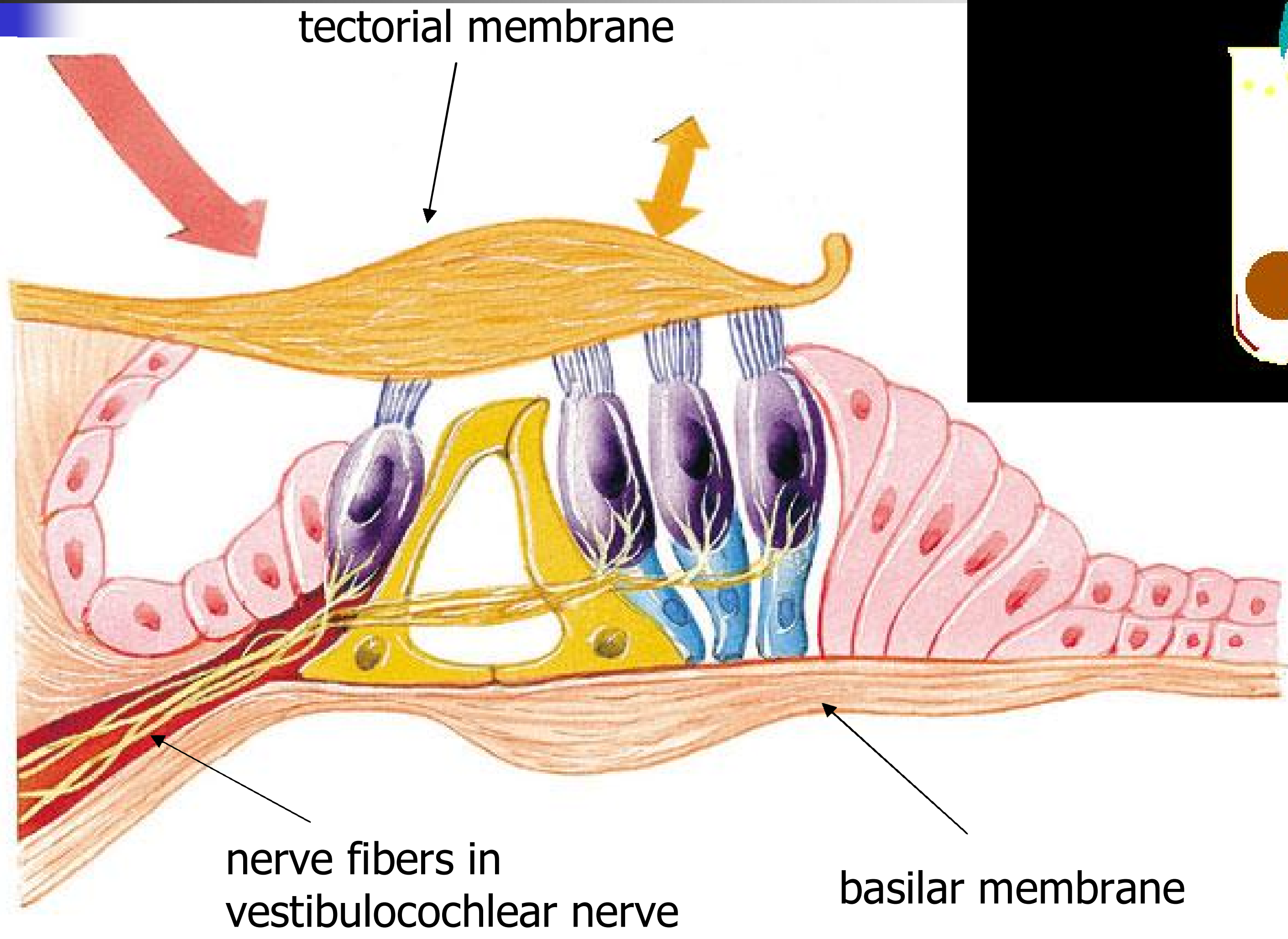


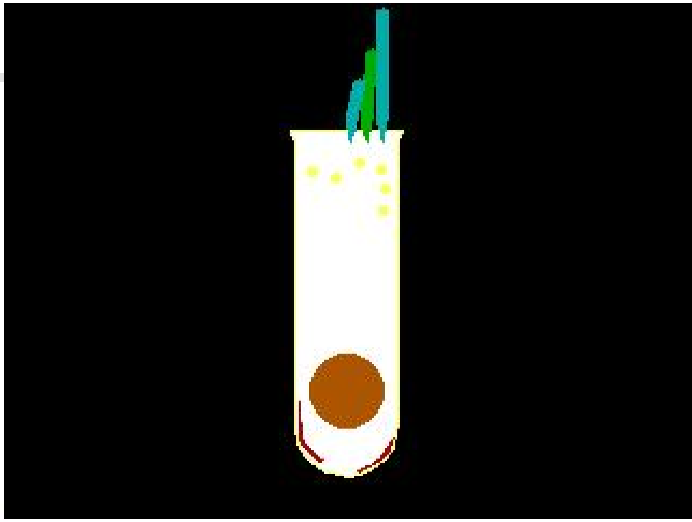




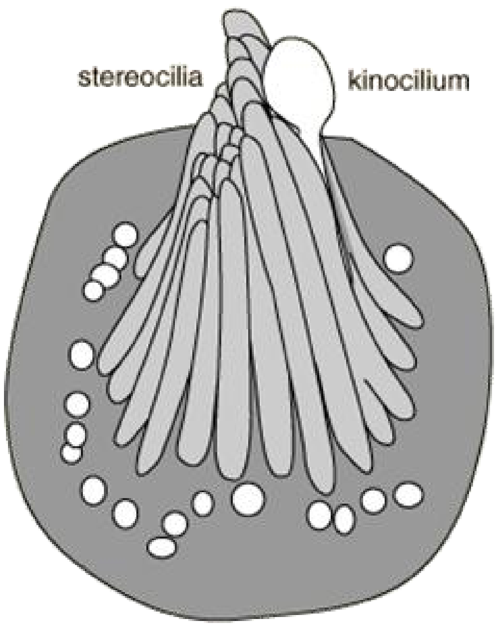
Adapted from electron-scanning micrograph at 16,800x . A. J. Hudspeth, R. Jacobs, Science News, Oct 20, 1984.

Organ of Corti

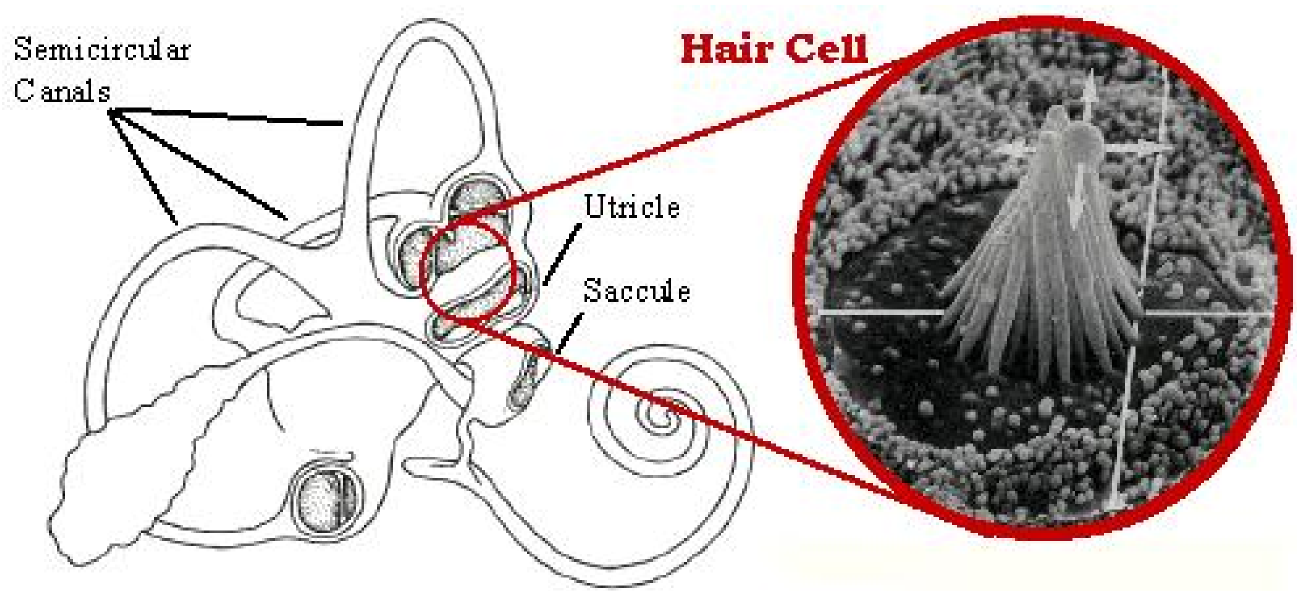




Stereocilla

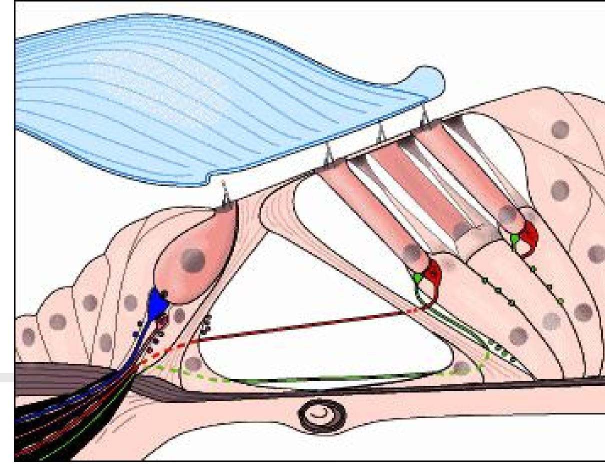


Adapted from electron-scanning micrograph at 16,800x . A. J. Hudspeth, R. Jacobs, Science News, Oct 20, 1984.

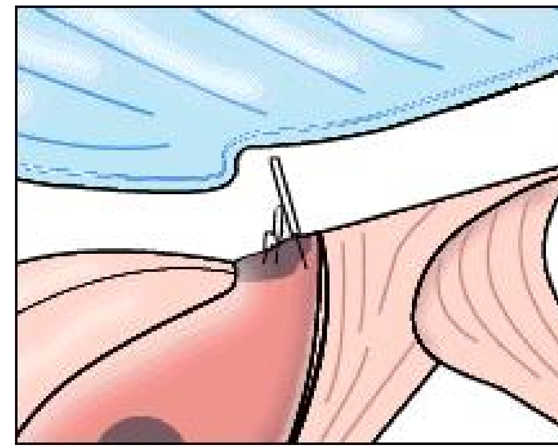


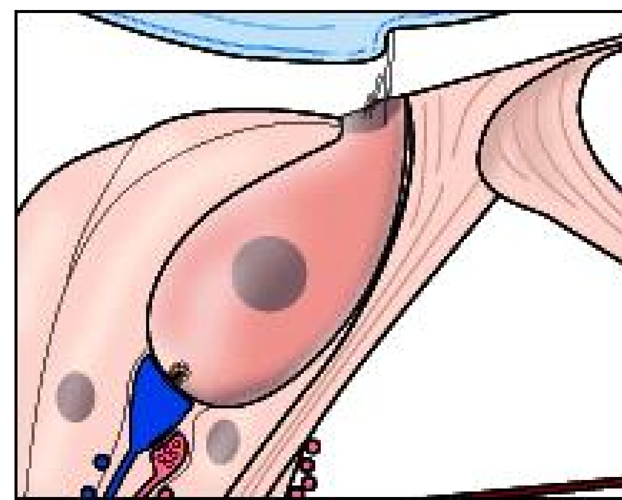
Hair cells have stereocilla and kinocilium (true cillia)

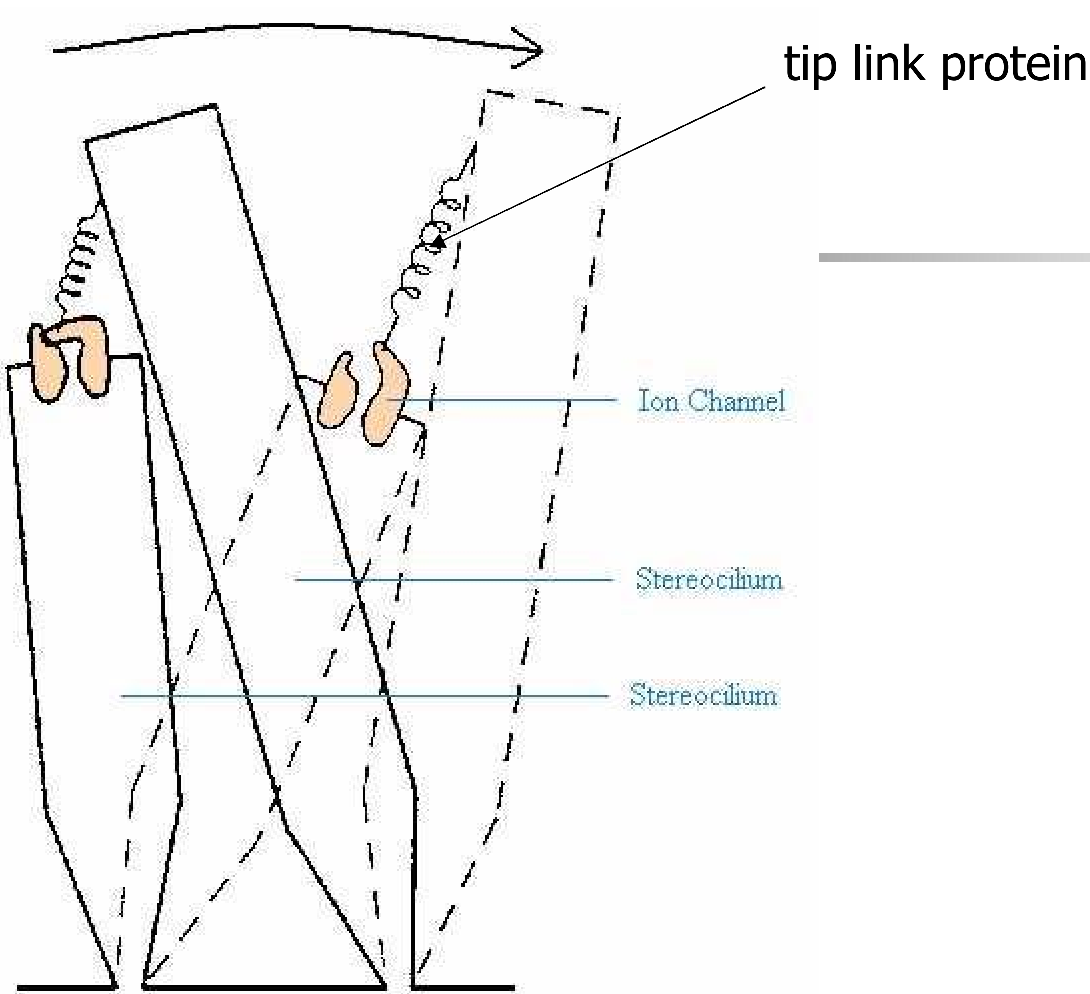
Organ of Corti

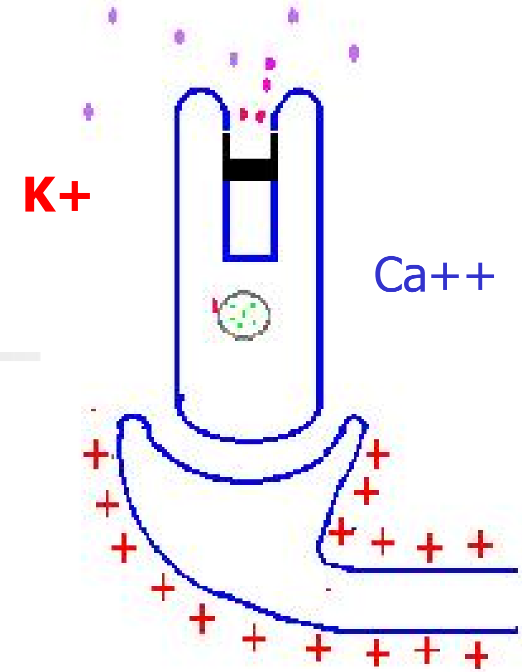


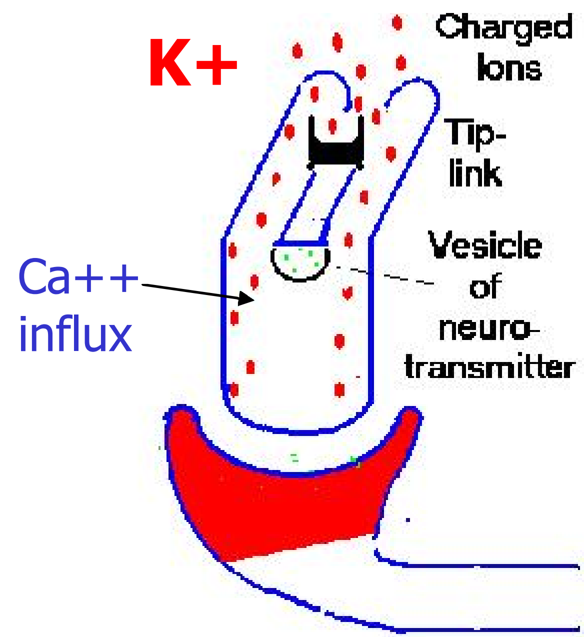
- When the cochlear duct is displaced, a shearing force is created, moving and bending the stereocilia.
- Ion channels open, depolarizing the hair cells, releasing glutamate that stimulates the sensory neuron.
- Greater bending of stereocilia, the increased frequency of AP produced.
- Nerve impulses in cochlear nerve travel to brain stem and on to the auditory areas of cerebral cortex, where it is interpreted as sound.



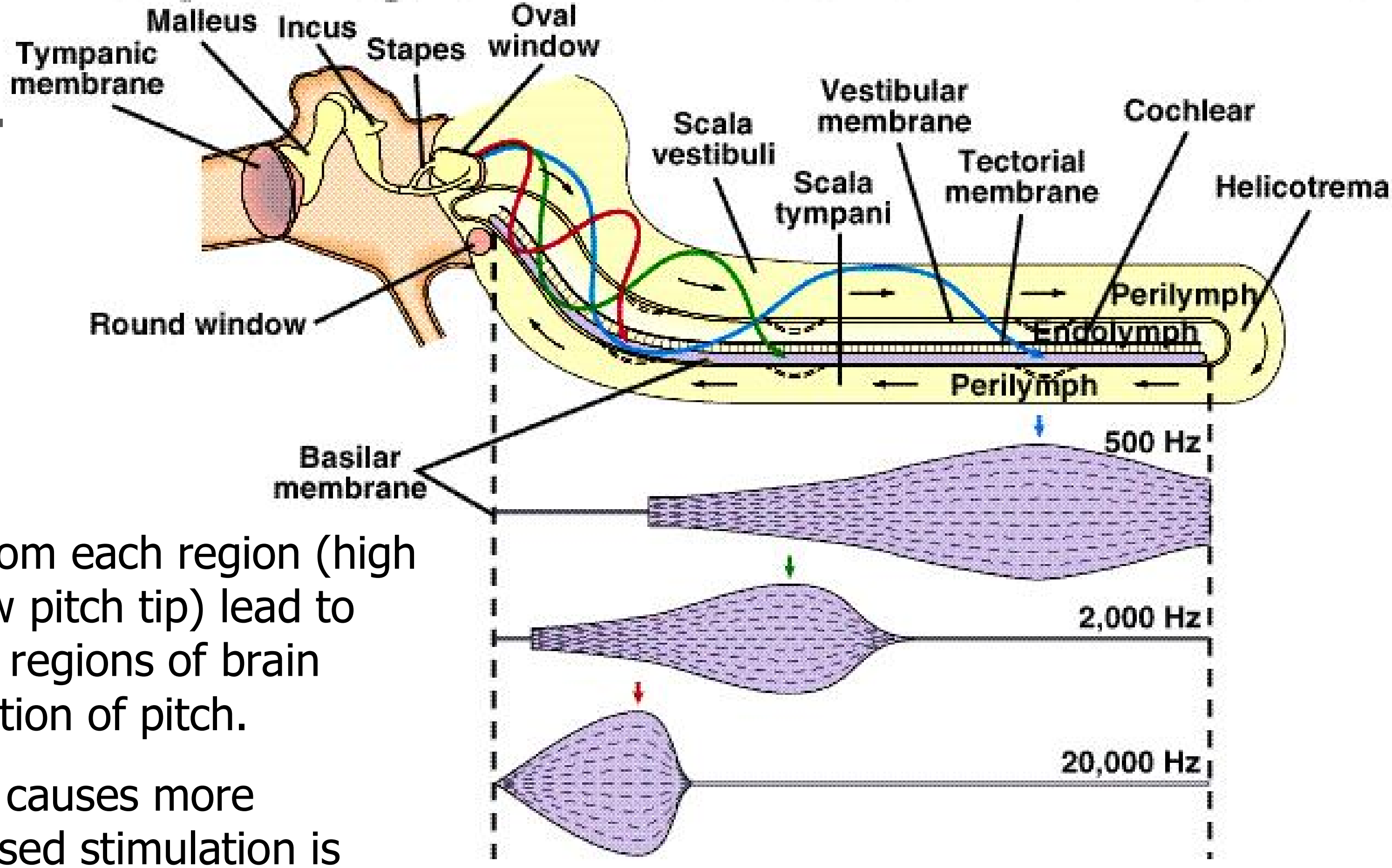



tip link protein
Ion Channel
Stereocilium
Stereocilium


K+
Ca++

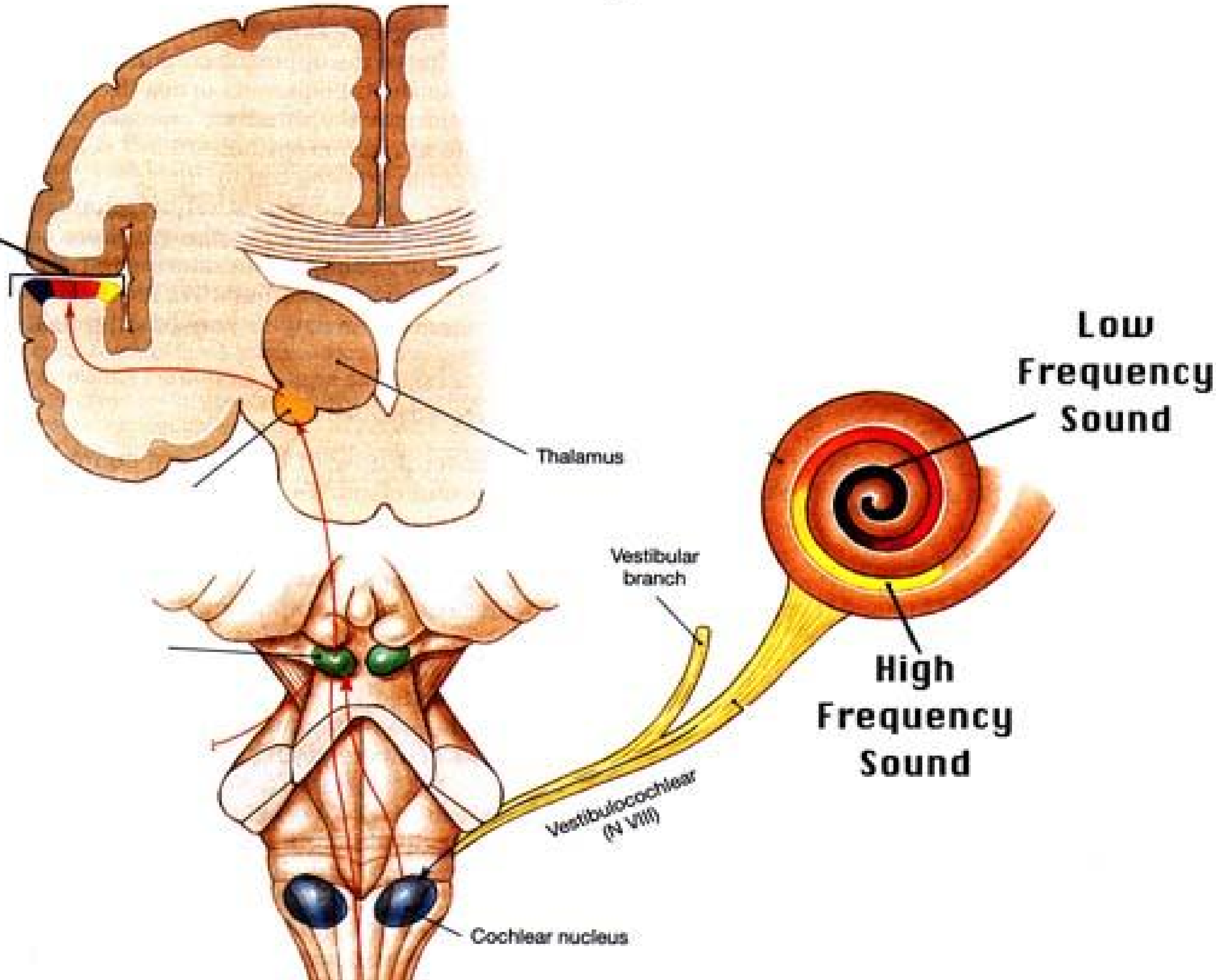

K+
Charged Ions
Tip-link
Vesicle of neuro-transmitter
Ca++ influx

Effect of Sounds of Different Frequency on the Basilar Membrane



- Nerve fibers from each region (high pitch base or low pitch tip) lead to slightly different regions of brain producing sensation of pitch.
- Sound volume causes more vibration; increased stimulation is interpreted as louder sound intensity.
- Tone is interpretation of brain based on distribution of hair cells stimulated.

Pitch Map on Auditory Cortex



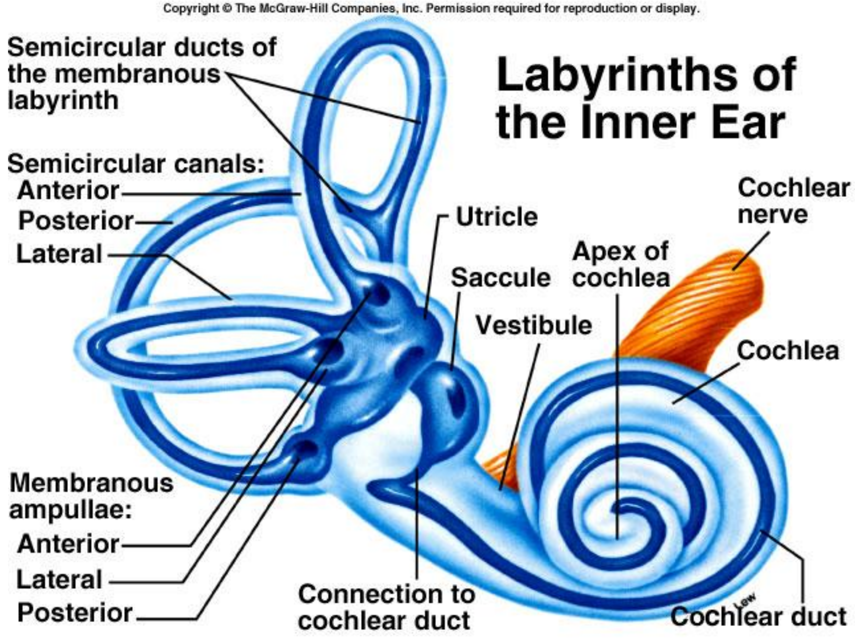
Modified from Martini Timmons, Prentice Hall, 1997

Vestibular Apparatus and Equilibrium

- Vestibular apparatus maintains the body (mainly the head) at equilibrium (at balance) and stabilizing the eyes relative to the environment
  - Static equilibrium- maintenance of the position of the body (mainly the head) relative to the force of gravity
  - Dynamic equilibrium- maintenance of the position of the body (mainly the head) in response to sudden movements such as rotation, acceleration, and deceleration.
- Consists of 2 parts:
  - Otolithic organs
    - Utricle and saccule- static equilibrium
  - Semicircular canals- dynamic equilibrium

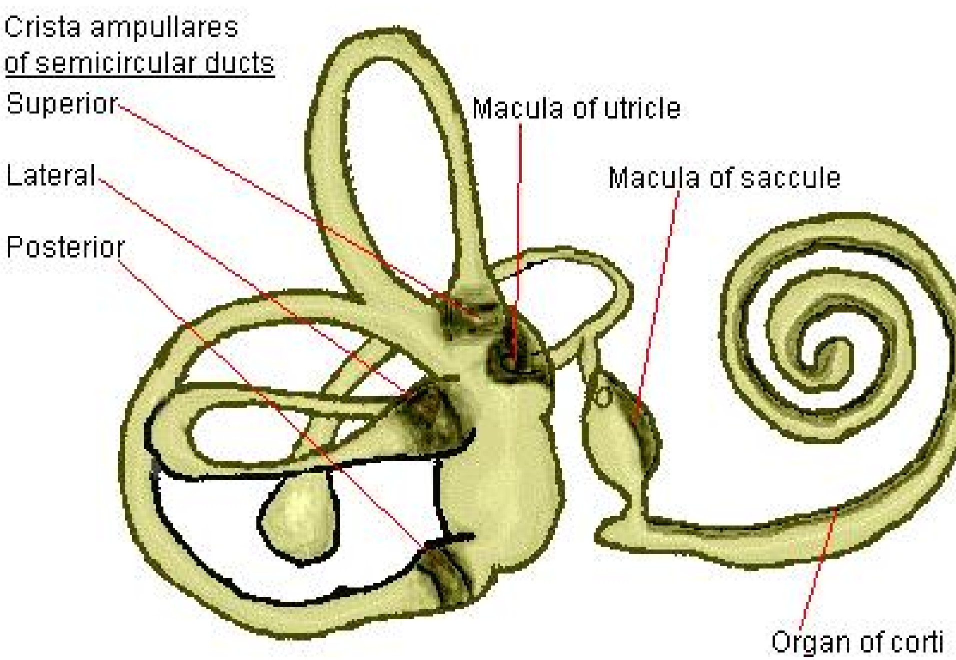
Vestibular apparatus

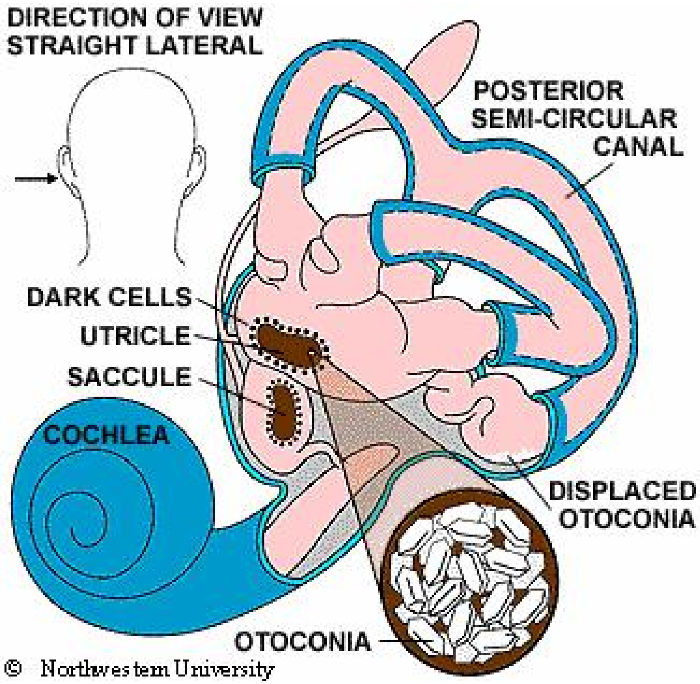
- Bony labyrinth surrounds membranous labyrinth filled with **endolymph** (like ECF).
- Between bony labyrinth and membrane of membranous labyrinth is **perilymph** (like CSF)

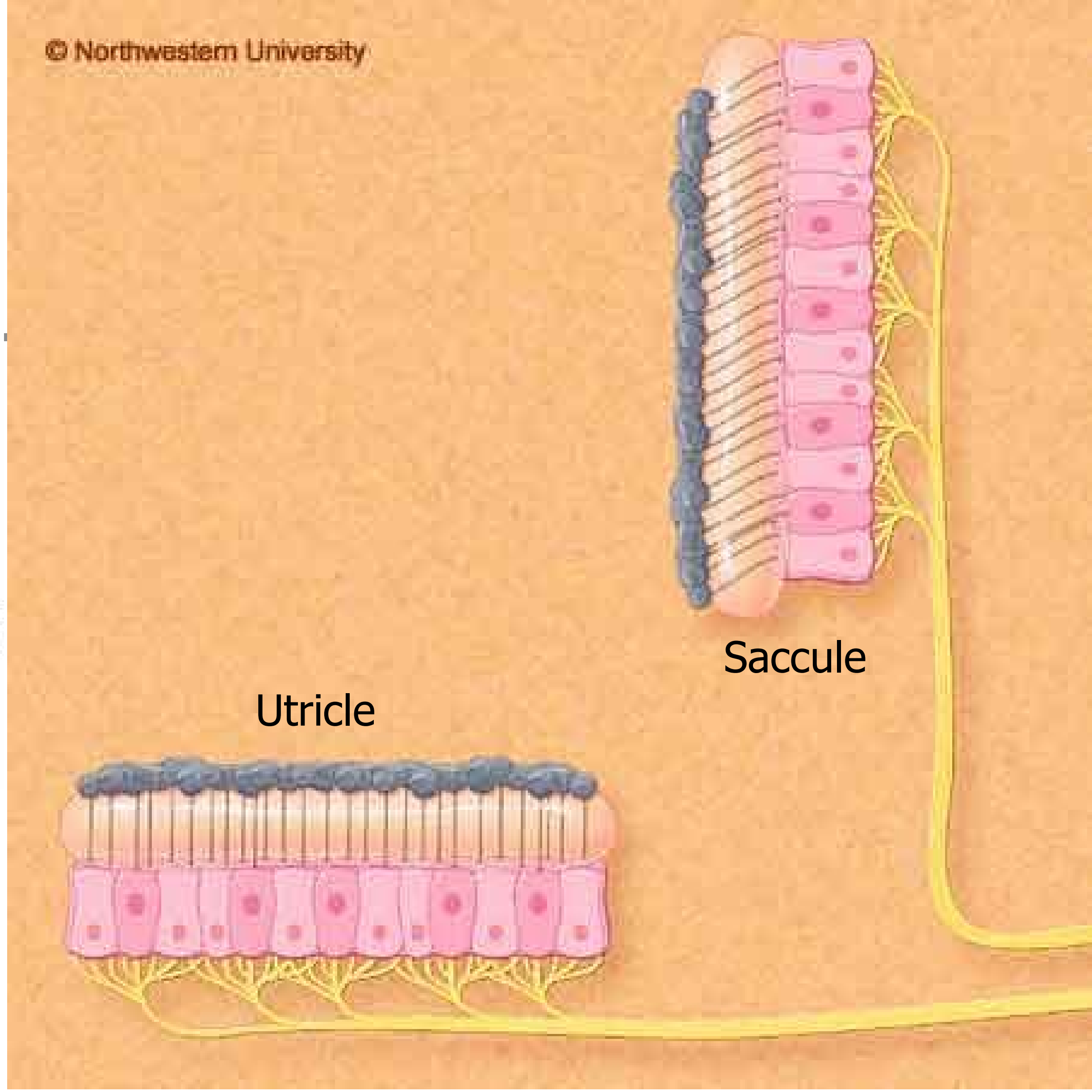


Vestibular apparatus: Otolithic organs

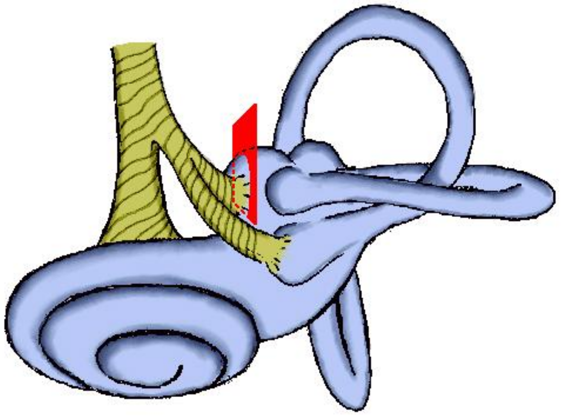
- Utricle and saccule
  - Saccule connected to utricle by duct.
- Each sensory area consist of a **macule** that contains the sensory mechanisms



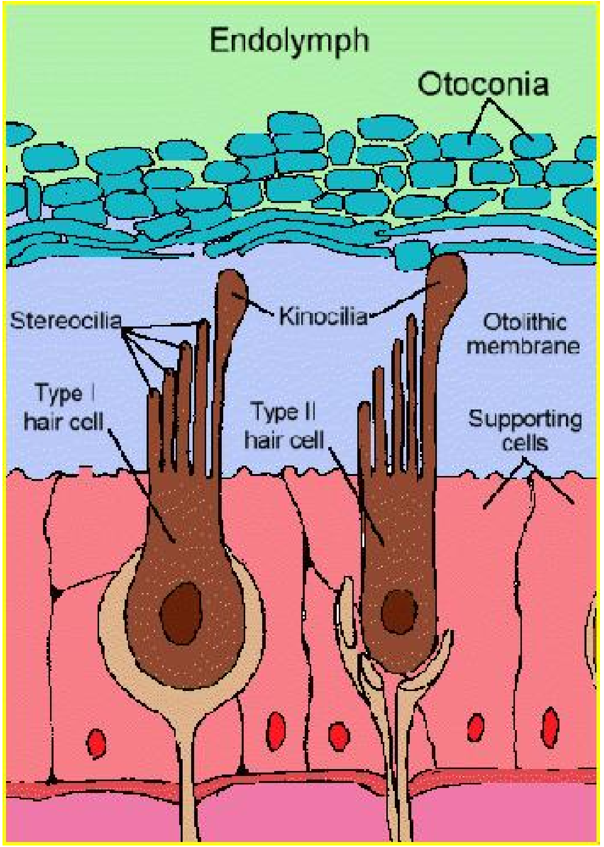

DIRECTION OF VIEW
STRAIGHT LATERAL
POSTERIOR
SEMI-CIRCULAR
CANAL
DARK CELLS
UTRICLE
SACCULE
COCHLEA
DISPLACED
OTOCONIA
OTOCONIA
© Northwestern University


© Northwestern University
Saccule
Utricle

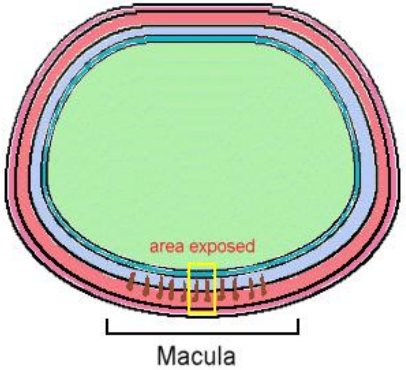
Utricle



- an irregular, oblong membranous sac located on the medial wall of the vestibule.
- lies horizontally
  - More sensitive to horizontal acceleration.
- macula consist of sensory hair cells and supporting cells (sustentacular cells)

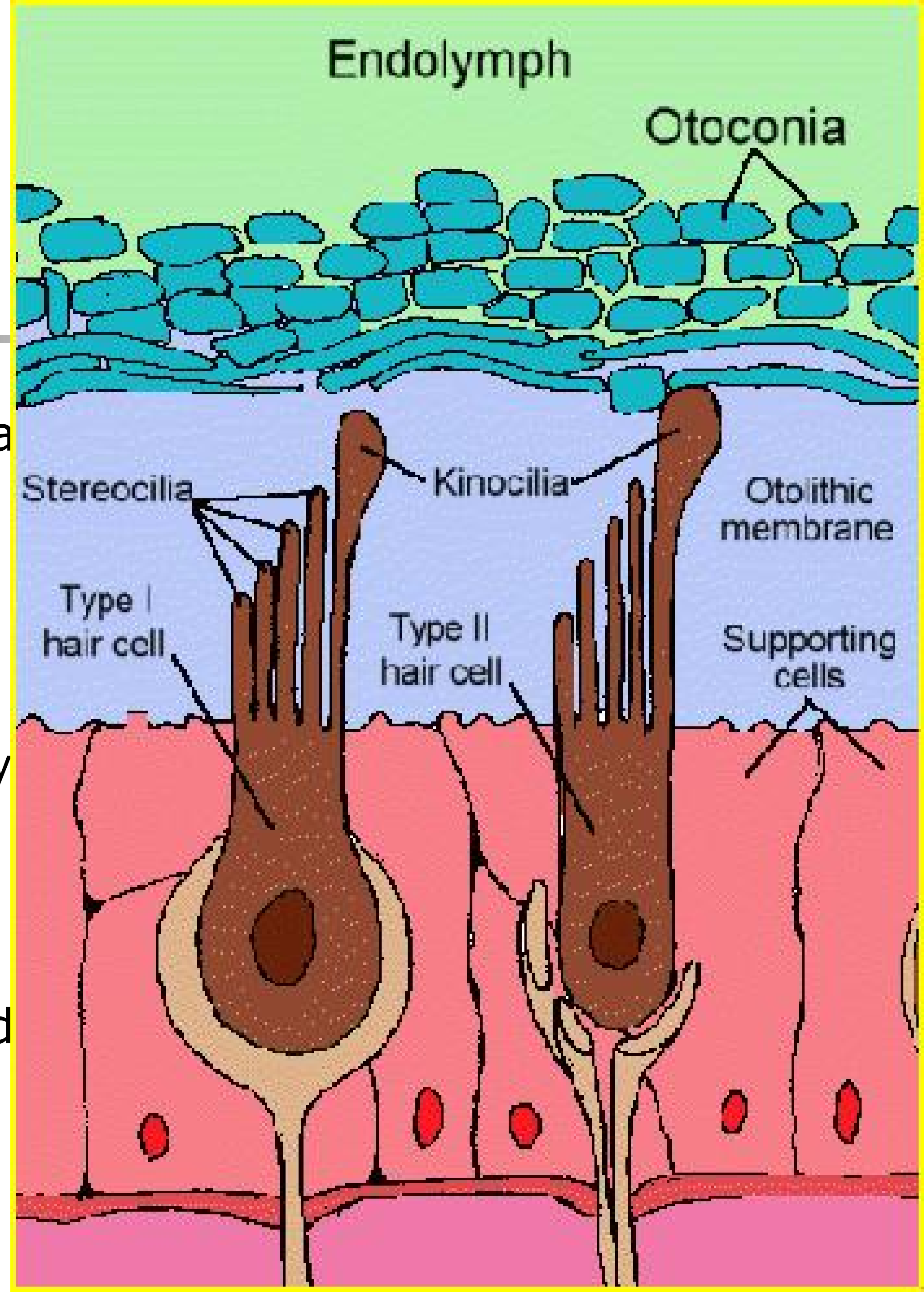


Cross-section of utricle



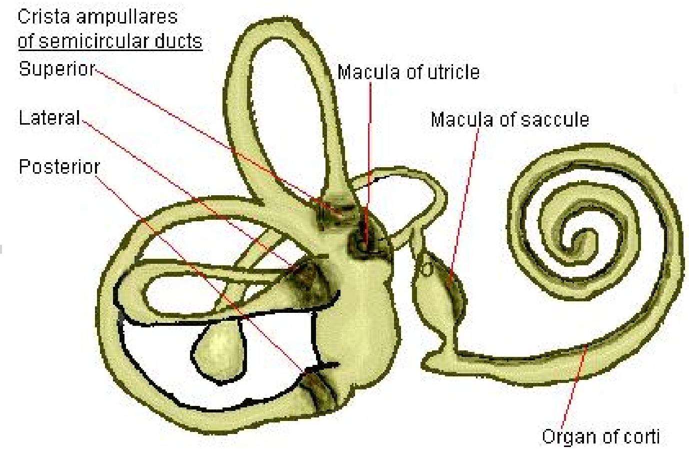
Utricle

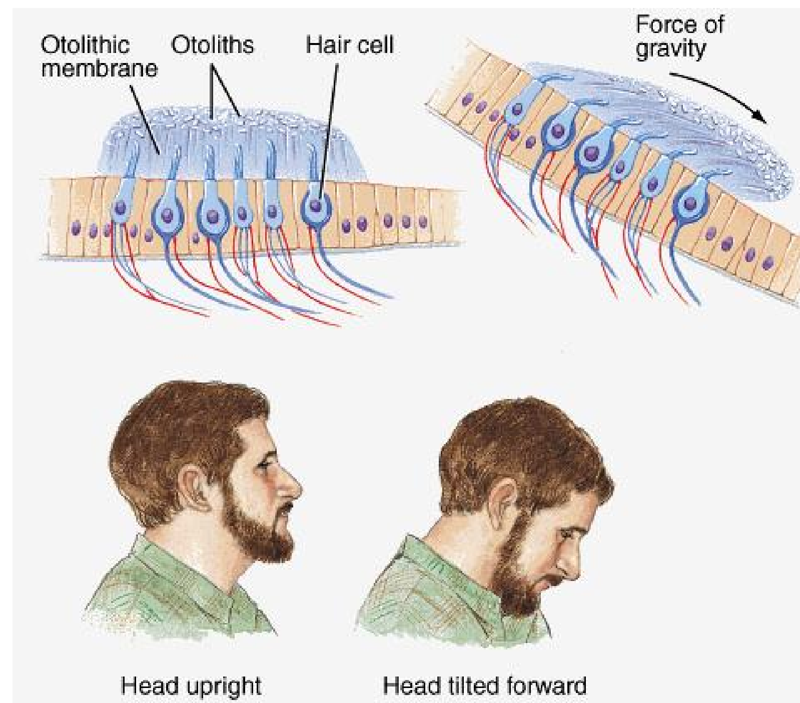
- Each sensory hair cell has one kinocilium and many stereocilia
- The stereocilia and kinocilium are embedded in a gelatinous membrane, the ***otolithic membrane***, which sits on top of the sensory cells.
  - The membrane is produced by the sustentacular cells.
- On the surface of the otolithic membrane are ***otoliths*** **(or otoconia),** crystals of Ca^{++} carbonate which are composed of calcium carbonate and protein.
  - These otoliths sensitive to horizontal movements



Saccule

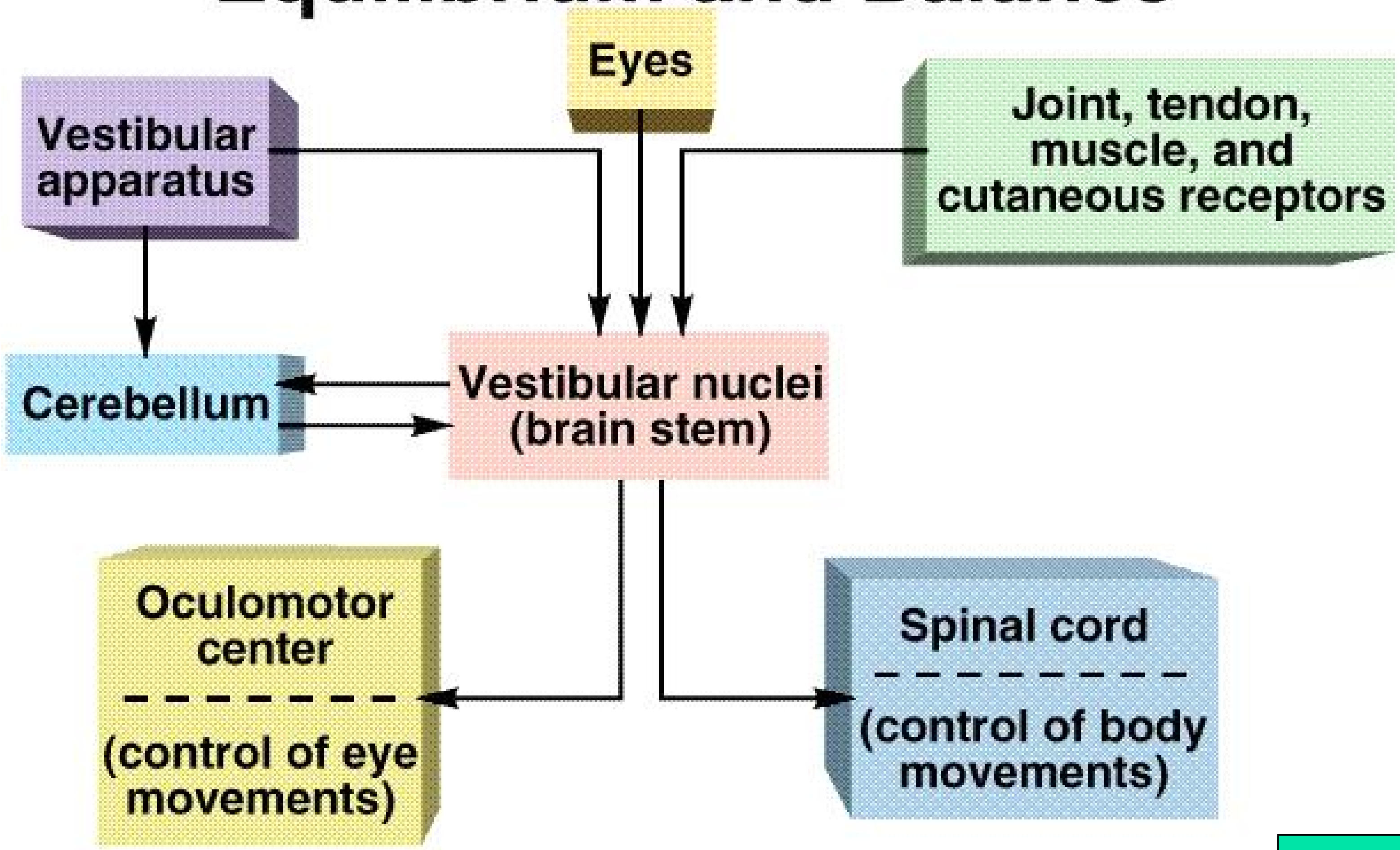
- a flattened, irregularly-shaped membranous sac also located in the medial wall of the bony vestibule.
- *saccular macula*, having the same struture as the utricle, lies perpendicular and verticle to the macula of the utricle.
  - More sensitive to vertical (saggital plane, up and down forward and back) acceleration.
- has two small openings are present in the saccule.
  - One is the opening of a duct, called the *endolymphatic duct*, that communicates with the utricle.
  - The other opening communicates with the duct of the cochlea via the *ductus reuniens*.



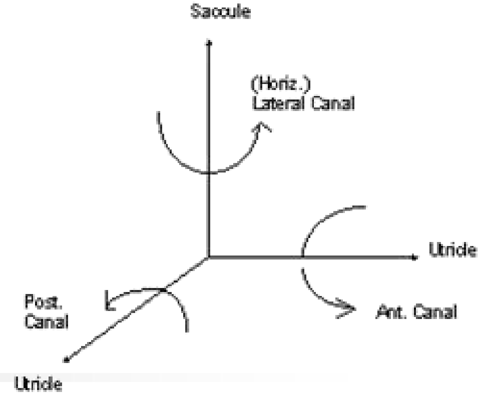


Position of macula with head upright (left) and tilted forward (right)

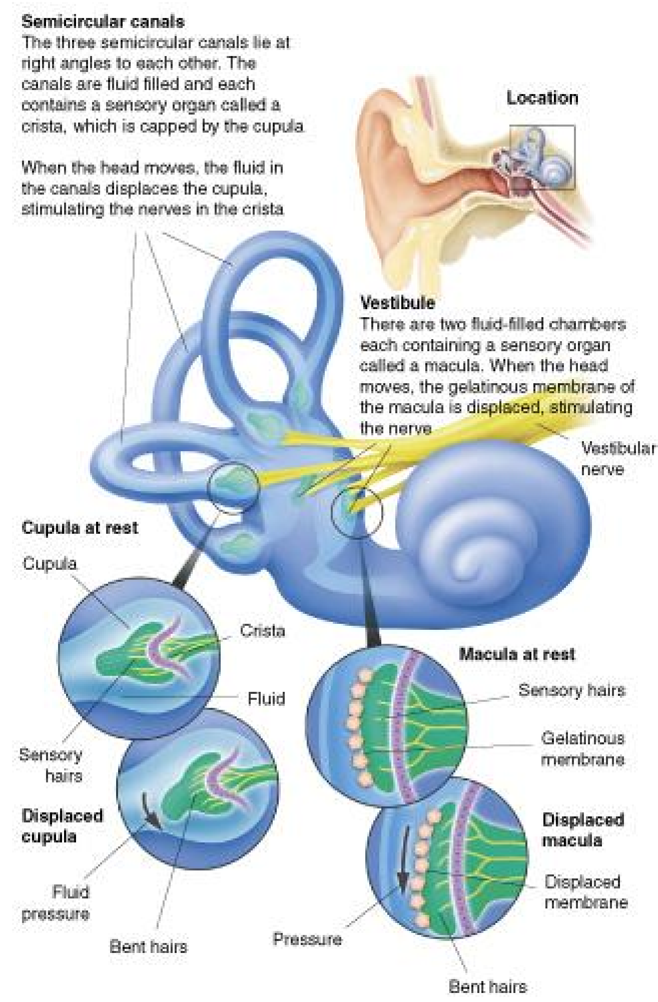
Neural Pathways Involved in the Maintenance of Equilibrium and Balance



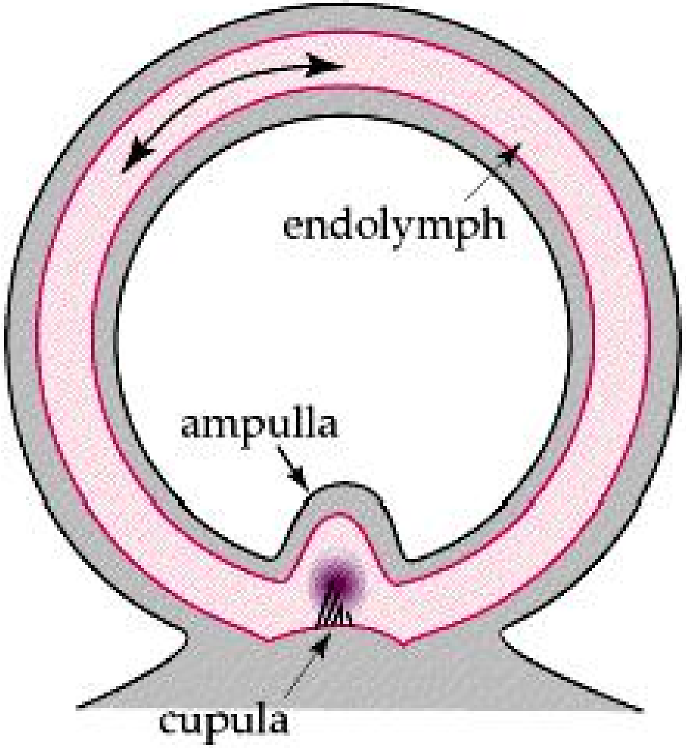
Semicircular Canals

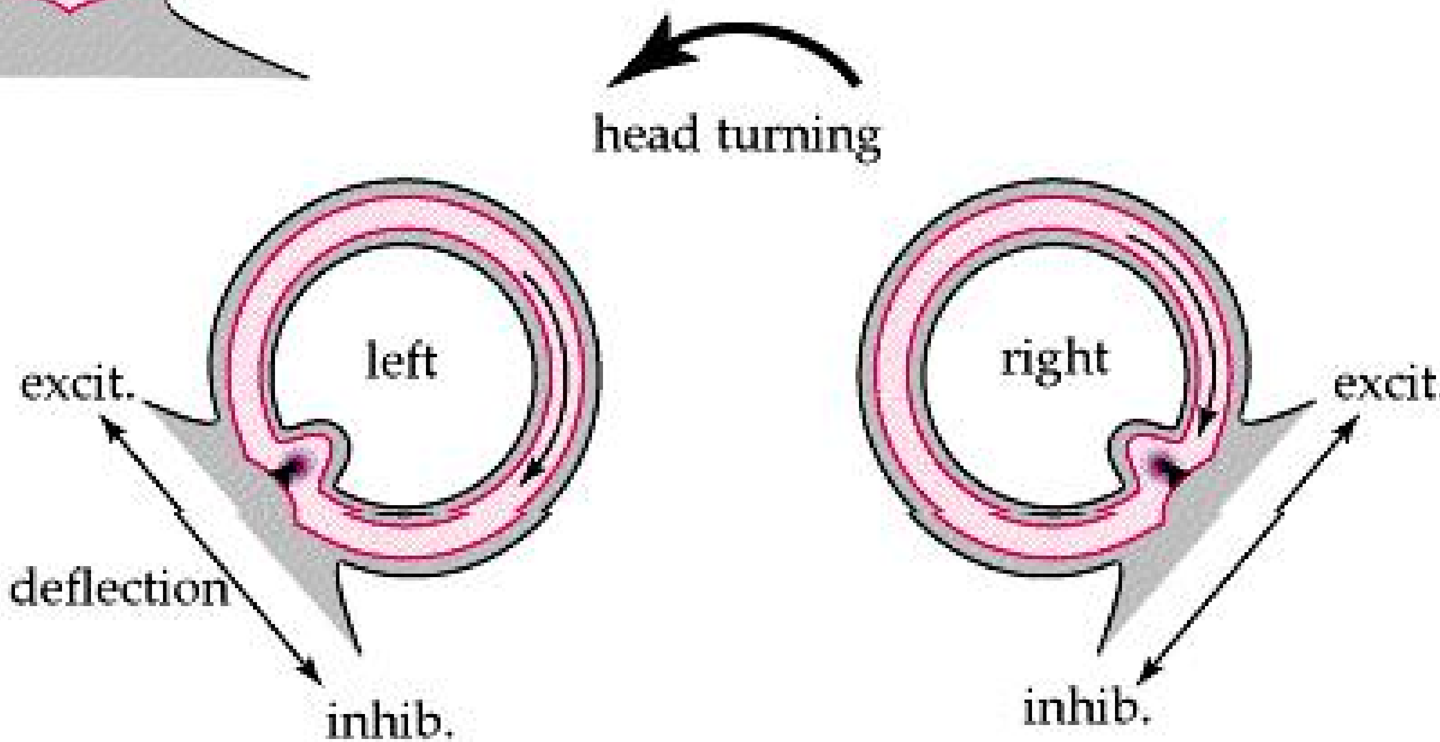


- Provide information about rotational acceleration.
- Project in 3 different planes.
- Each canal contains a semicircular duct. At the base is the **crista ampullaris**.
  - = enlarged swellings at base of each canal communicating with utricles

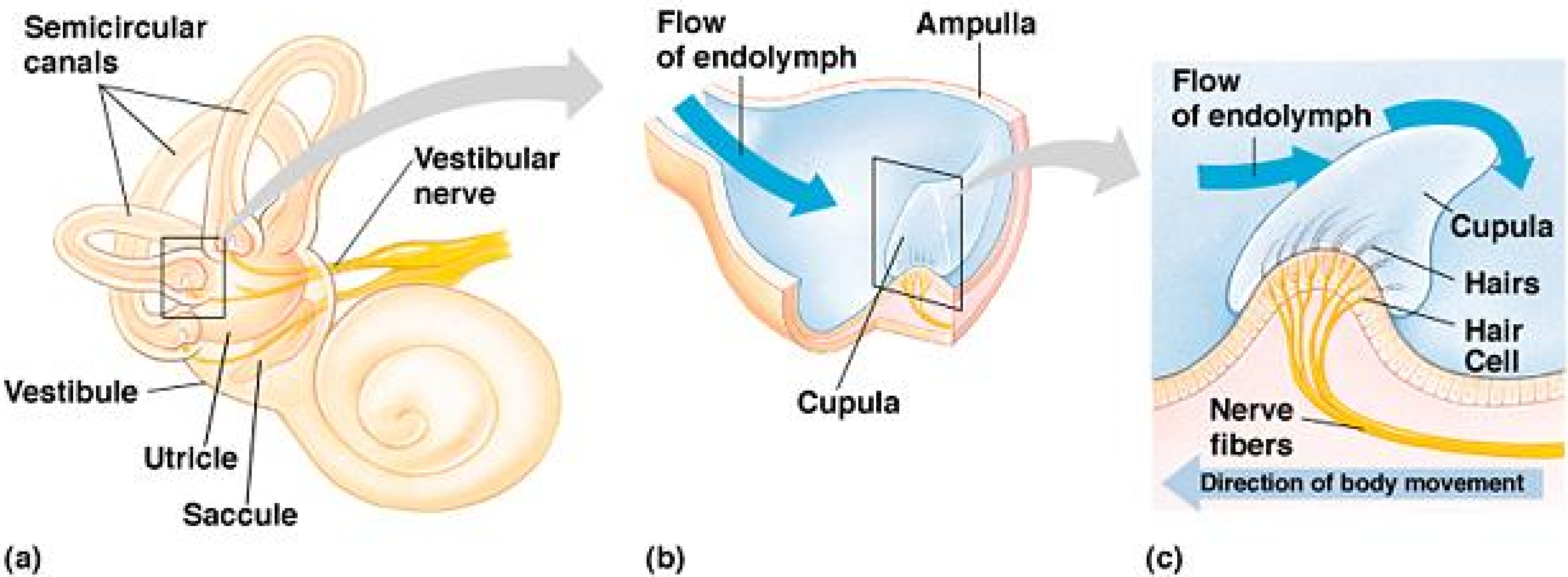


Endolymph Movement in Canals

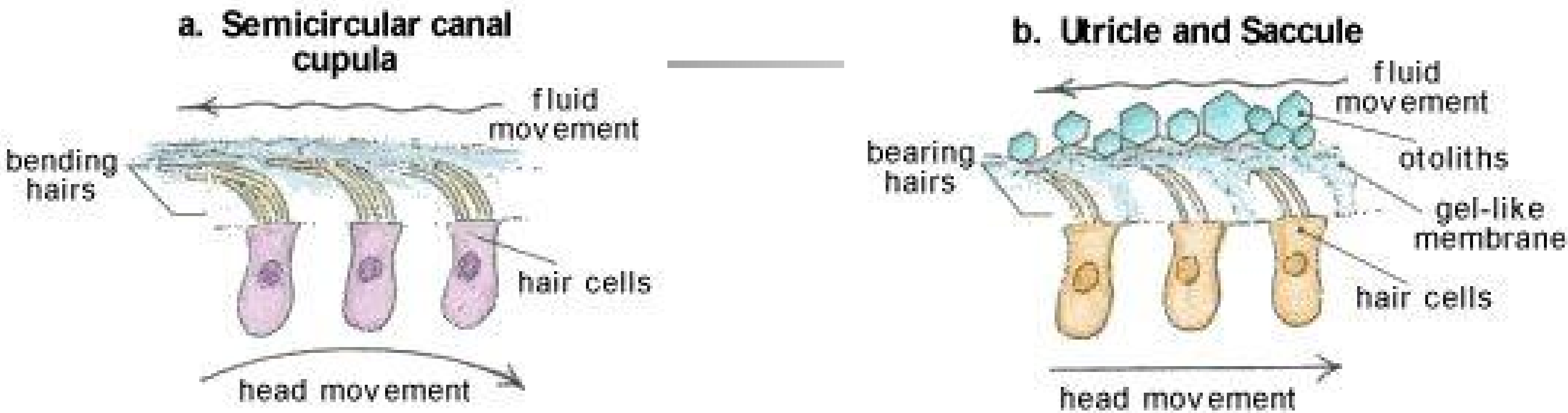


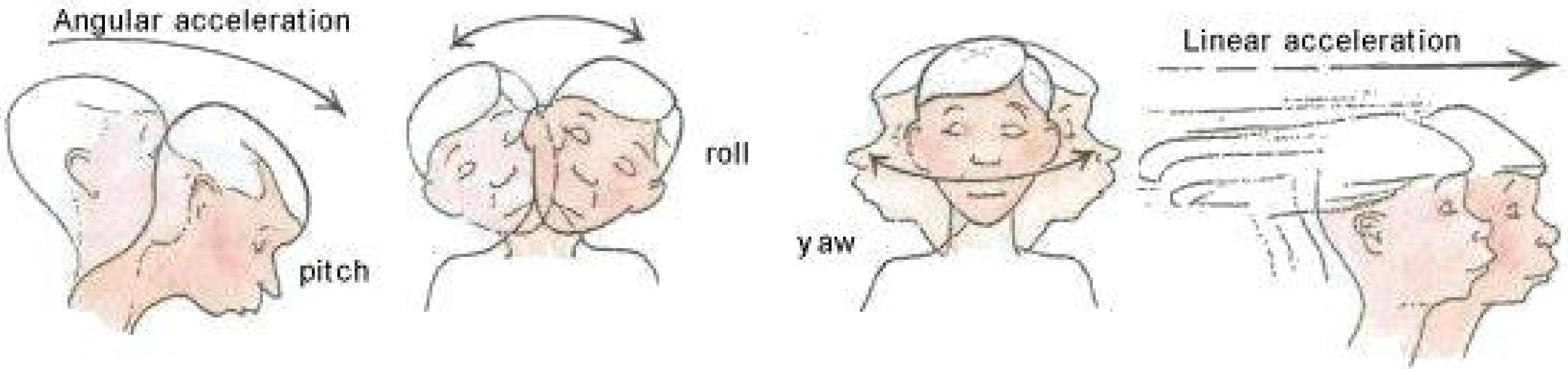


Movement of Cupula Relative to Body Movement



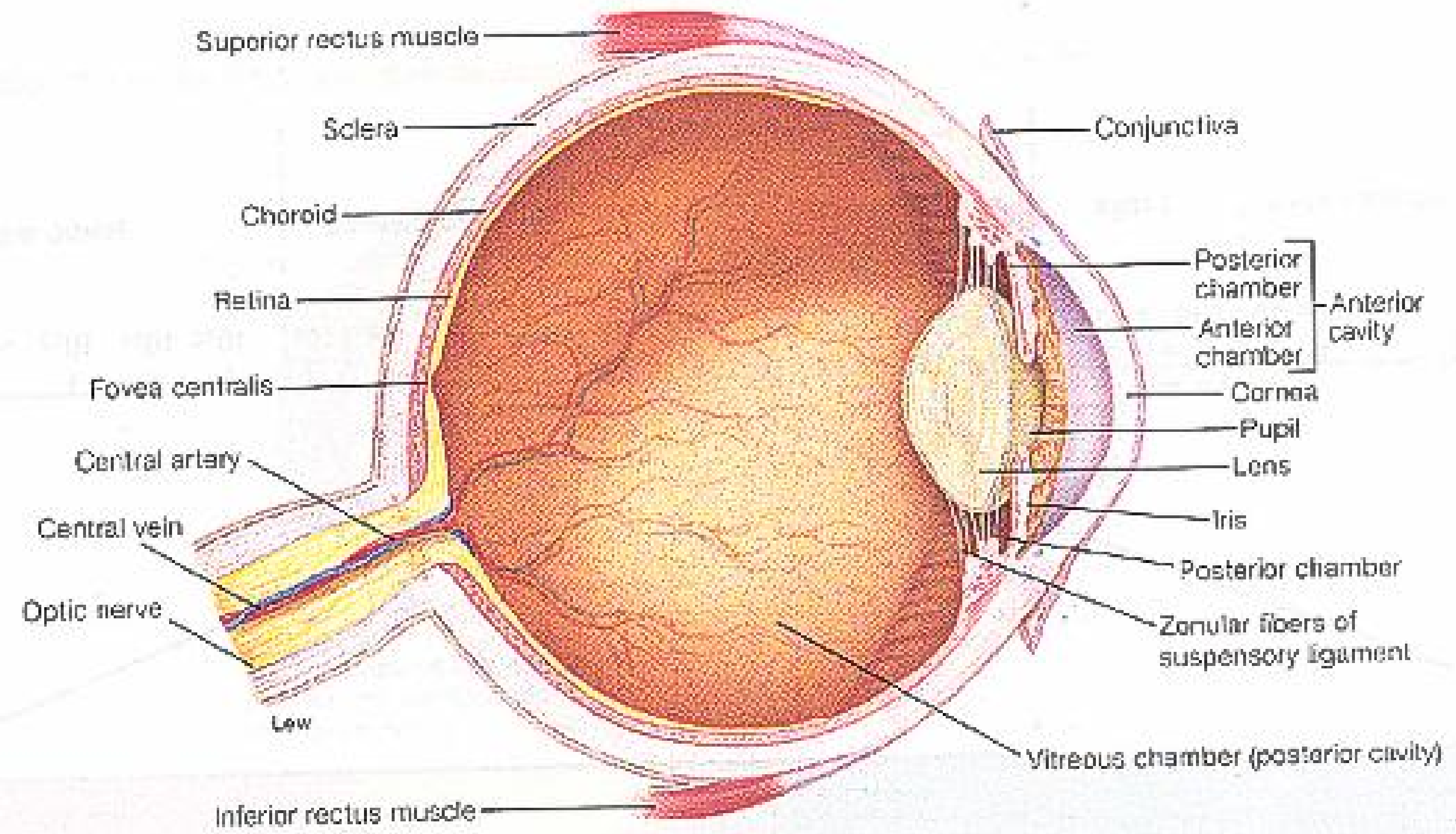
- Endolymph provides inertia so that the sensory processes will bend in direction opposite to the angular acceleration.


a. Semicircular canal cupula
fluid movement
bending hairs
hair cells
head movement
b. Utricle and Saccule
fluid movement
otoliths
bearing hairs
gel-like membrane
hair cells
head movement



- **The semicircular canals are responsible for detecting any kind of rotational motion in the head (pitch, roll, yaw).**
- **The otolith organs (utricle and saccule) are primarily responsible for detecting any degree of linear motion of the head.**
  - head is tilted to one side
  - accelerated forward and back, or side to side
  - accelerated up and down (as in an elevator),

The Eye


Superior rectus muscle
Sclera
Choroid
Retina
Fovea centralis
Central artery
Central vein
Optic nerve
Conjunctiva
Posterior chamber
Anterior chamber
Anterior cavity
Cornea
Pupil
Lens
Iris
Posterior chamber
Zonular fibers of suspensory ligament
Vitreous chamber (posterior cavity)
Inferior rectus muscle

Outer Tunic

- **Sclera**.
  - Tough connective tissue layer. covers most of eyeball and forms visible white part of eye.
  - Protective
- **Cornea.**
  - Anterior transparent portion of sclera.
  - Window which helps focus light
  - Most blindness from cloudy cornea

Middle Tunic

- Choroid
- Ciliary body
- Iris
- Lens

Choroid

- Highly pigmented layer which contains many blood vessels to nourish retina.
- Posterior 5/6 of eyeball
- Anterior portion becomes specialized into ciliary body and iris.

Ciliary body

- Rings eye forward from choroid.
- Controls lens shape for <u>accommodation.</u>
- Produces <u>aqueous humor</u> (fluid which nourishes non-vascular tissues of cornea and lens).

Iris

- Anterior to ciliary body.
- Gives eye its color.
- Controls size of pupil and how much light enters eye.

Lens

- For focusing light on retina.
- Separates interior of eye into 2 compartments.
- Anterior cavity has **aqueous humor**
- Larger posterior cavity between lens and retina has **vitreous humor.**

Posterior Cavity

- Vitreous humor in posterior cavity is semifluid, jellylike substance.
- Enables eye to retain its spherical shape.
- Failure to drain will --> increased pressure inside of eye = **glaucoma**. Pushes lens backward into vitreous humor, which is, in turn, pushed into retina. Can cause damage and blindness if not treated.

Inner Tunic

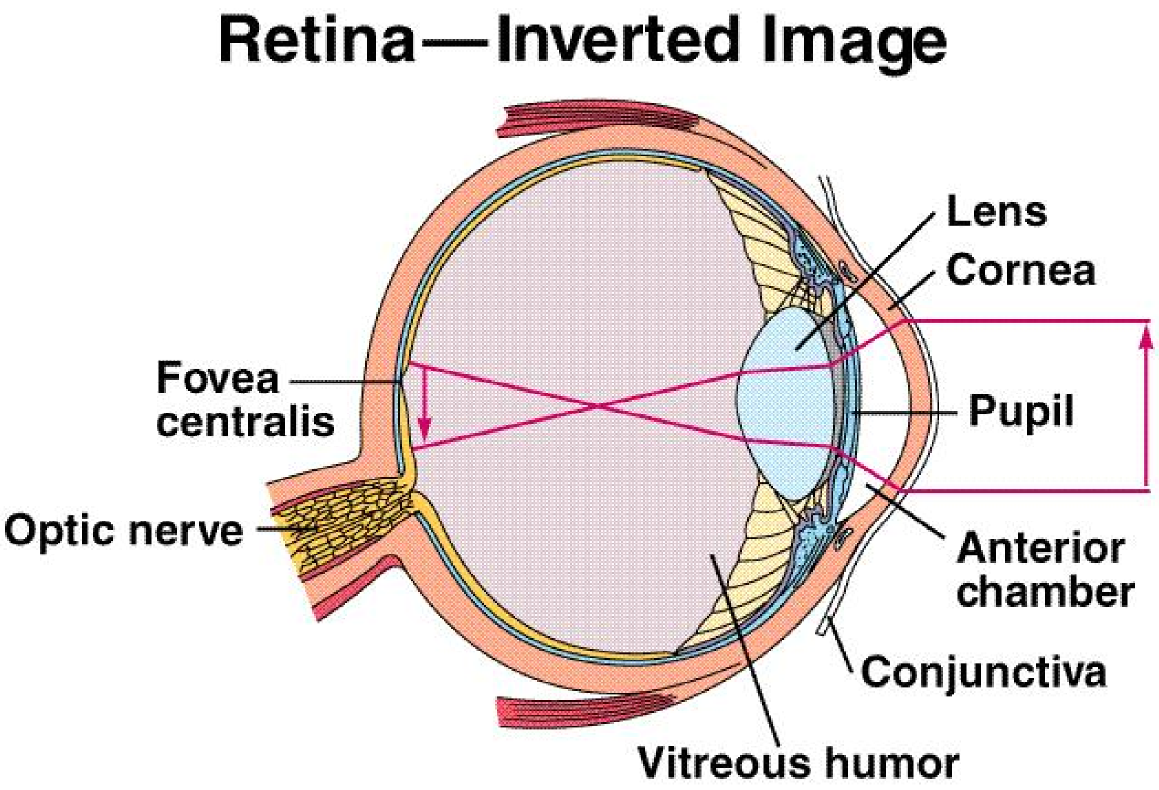
- Consists of retina.
- Retina has 4 layers
  - Pigmented epithelium
  - Receptor cells (rods and cones)
  - Layer of <u>bipolar neurons</u>. Horizontal and amacrine neurons here too.
  - Layer of <u>ganglion cells.</u>

Vision

- Eyes transduce energy in the electromagnetic spectrum into APs.
- Only wavelengths of 400 – 700 nm constitute visible light.
- Neurons in the retina contribute fibers that are gathered together at the optic disc, where they exit as the optic nerve.

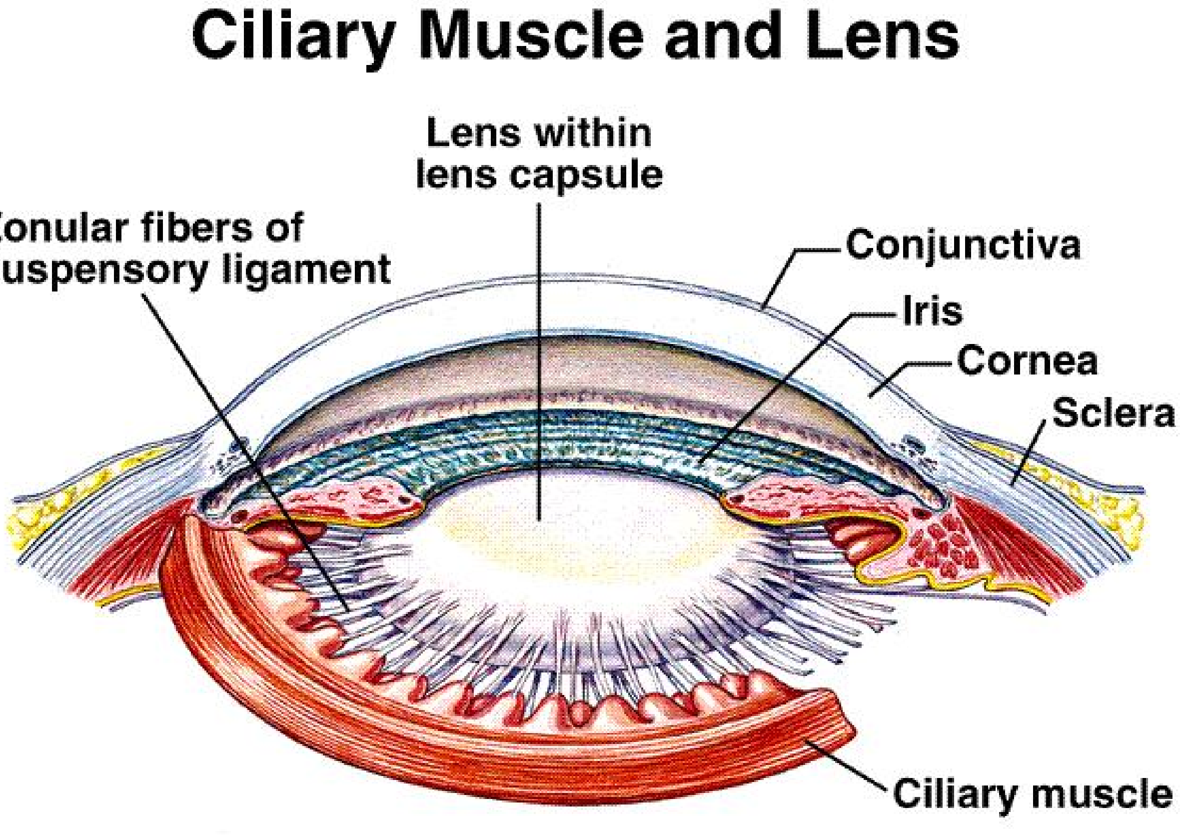
Refraction

- Light that passes from a medium of one density into a medium of another density (bent).
- Refractive index (degree of refraction) depends upon:
  - Comparative density of the 2 media.
  - Curvature of interface between the 2 media.
    - Refractive index of air = 1.00
    - Refractive index of cornea = 1.38
- Image is inverted on retina.



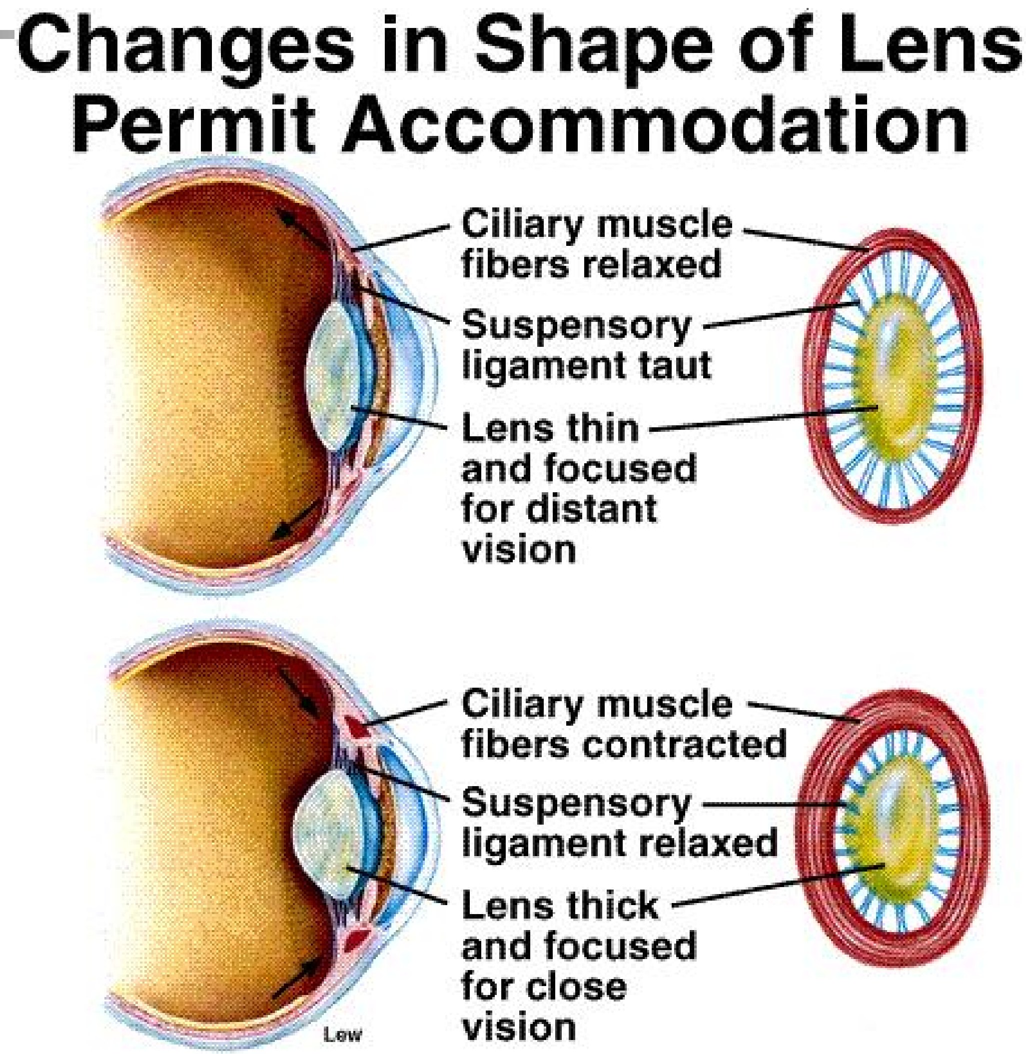
Accommodation

- Ability of the eyes to keep the image focused on the retina as the distance between the eyes and object varies.



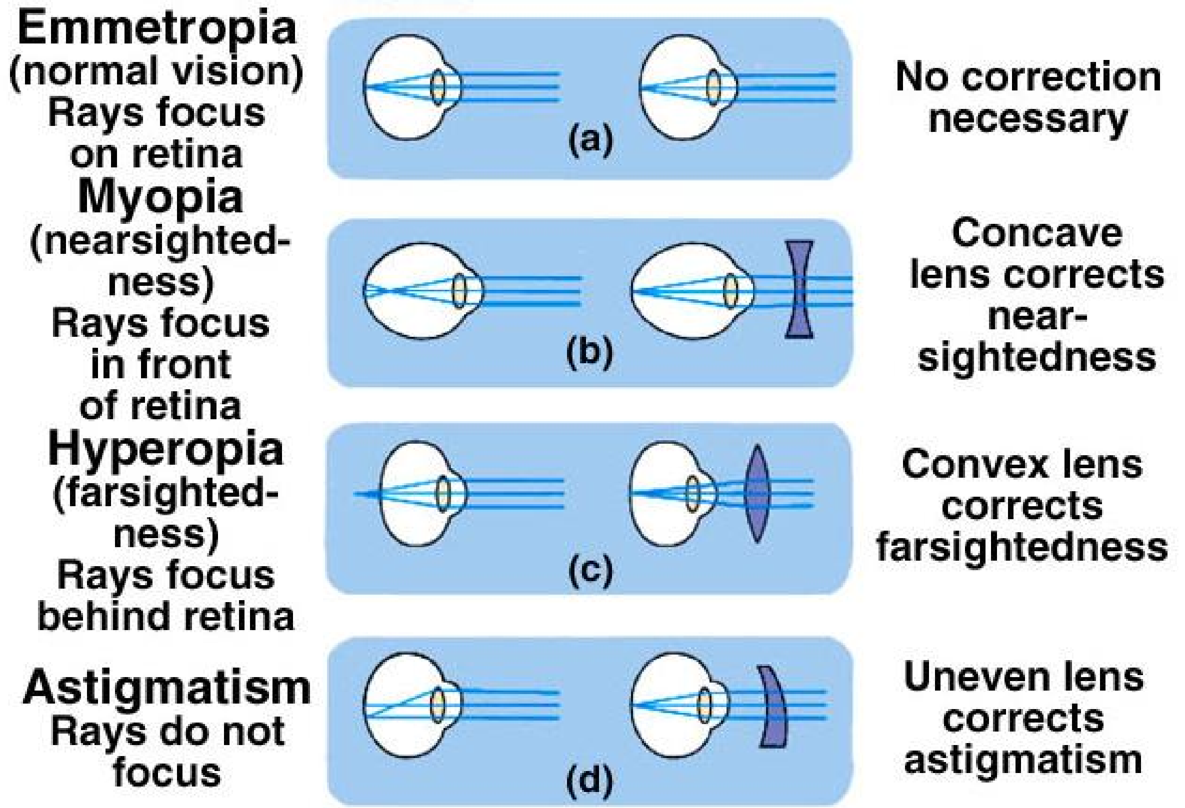
Changes in the Lens Shape

- Ciliary muscle can vary its aperture.
- Distance > 20 feet:
  - Relaxation places tension on the suspensory ligament.
  - Pulls lens taut.
  - Lens is least convex.
- Distance decreases:
  - Ciliary muscles contract.
  - Reduces tension on suspensory ligament.
  - Lens becomes more rounded and more convex.



Visual Acuity

- Sharpness of vision.
- Depends upon resolving power:
  - Ability of the visual system to resolve 2 closely spaced dots.
  - **Myopia** (nearsightedness):
    - Image brought to focus in front of retina.
  - **Hyperopia** farsightedness):
    - Image brought to focus behind the retina.



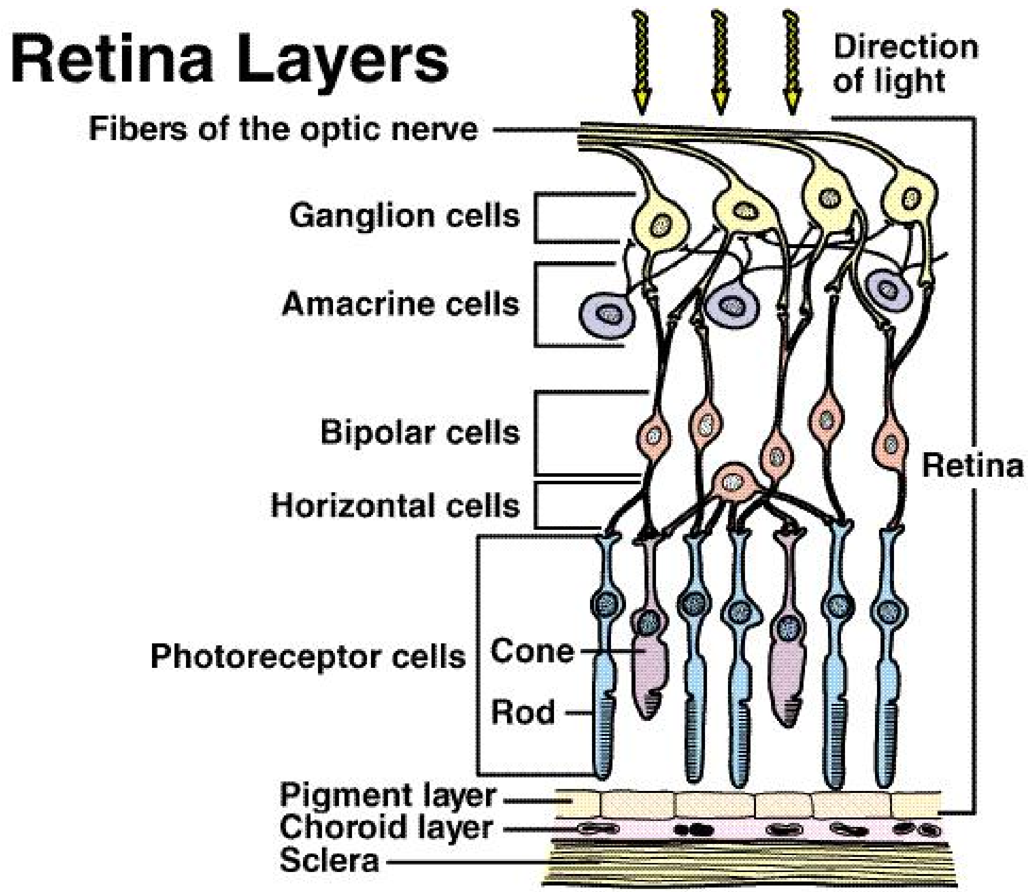
Refraction Problems and Corrections

Visual Acuity

- Astigmatism:
  - Asymmetry of the cornea and/or lens.
  - Images of lines of circle appear blurred.
- Corrected by cylindrical lens.

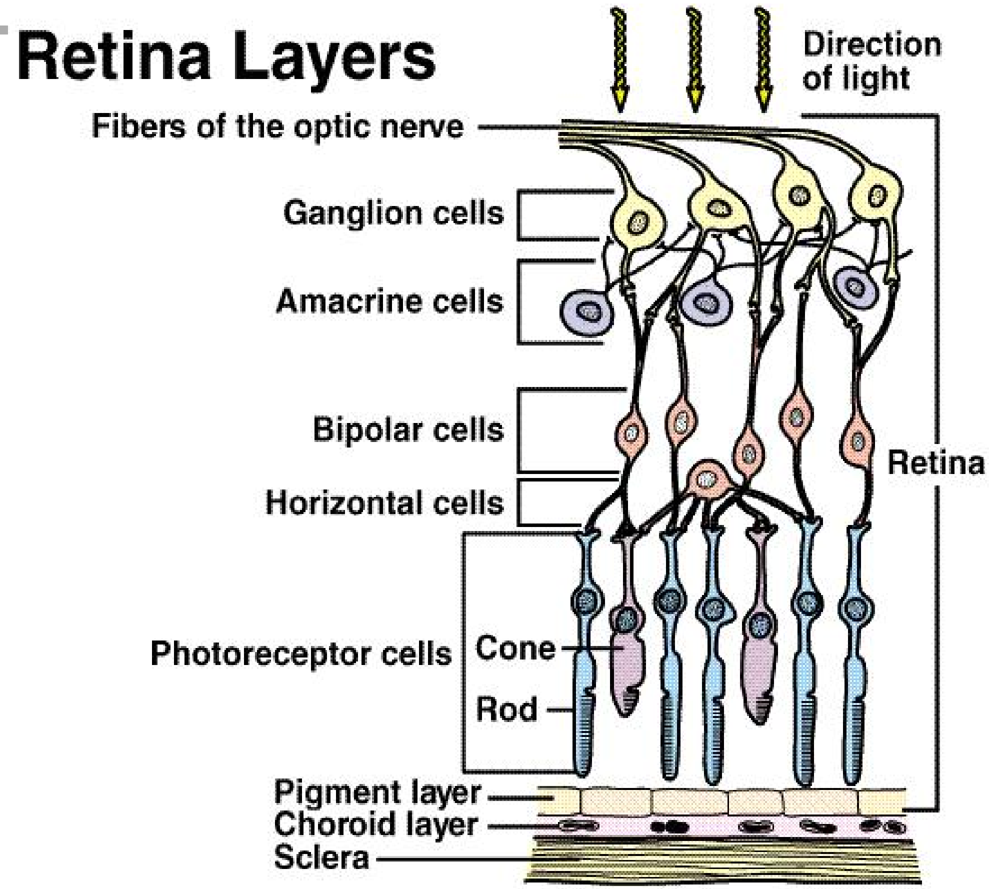
Retina

- Consists of single-cell-thick pigmented epithelium
- Photoreceptor neurons:
  - Rods and cones.
- Layers of other neurons
- Neural layers are forward extension of the brain.
  - Neural layers face outward, toward the incoming light.
  - Light must pass through several neural layers before striking the rods and cones.



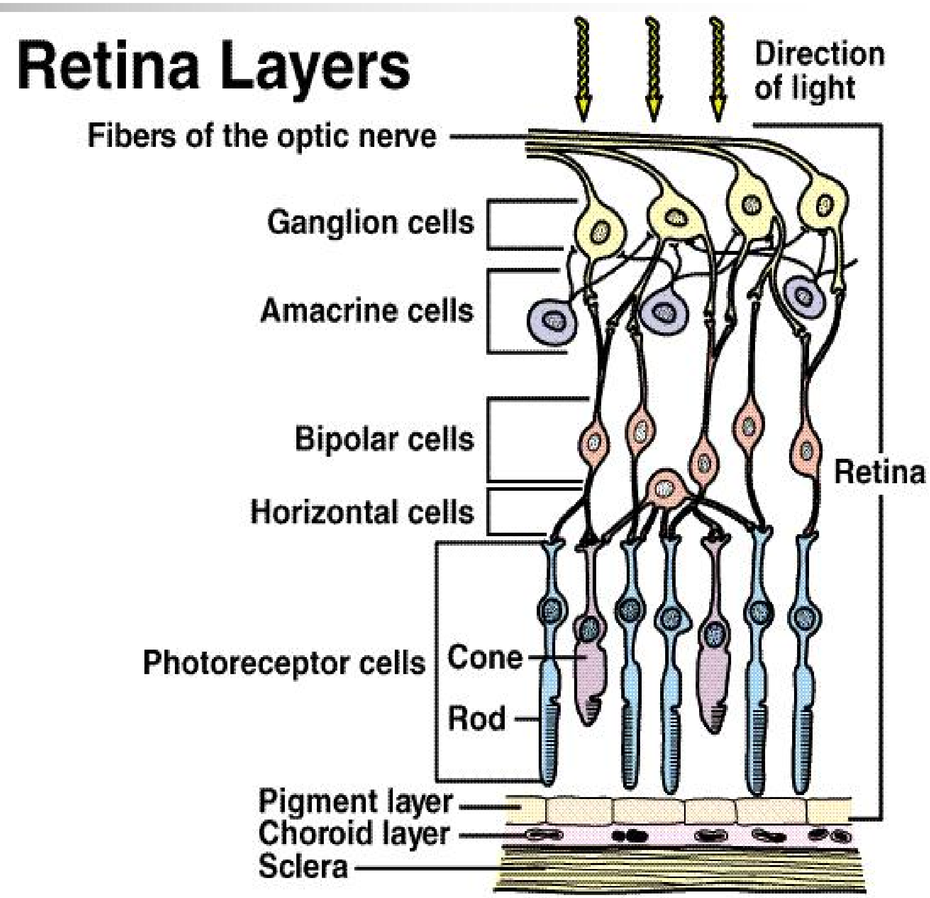
Retina

- Rods and cones synapse with other neurons.
- AP conducted outward in the retina.
- Outer layers of neurons that contribute to optic nerve called ganglion cells.



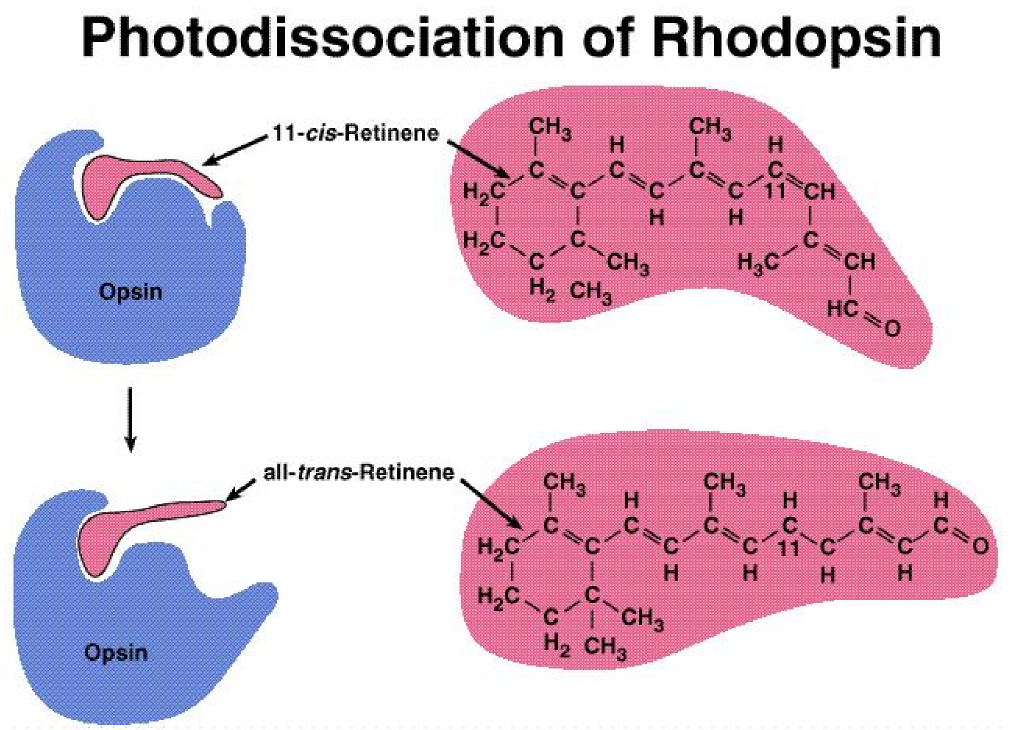
Retina

- Neurons receive synaptic input from bipolar cells, which receive input from rods and cones.
- Horizontal cells synapse with photoreceptors.
- Amacrine cells synapse with several ganglion cells.



Effect of Light on Rods

- Rods are activated when light produces chemical change in rhodopsin.
  - Bleaching reaction:
    - Rhodopsin dissociates into retinene (rentinaldehyde) and opsin.
      - 11-cis retinene is converted to all-trans form.
    - Initiates changes in ionic permeability to produce AP in ganglionic cells.
- Provide black-and-white vision.



Dark Adaptation

- Gradual increase in photoreceptor sensitivity when entering a dark room.
- Maximal sensitivity reached in 20 min.
- Increased amounts of visual pigments produced.
  - Slight increased pigment in cones.
  - Greater increased rhodopsin in rods.
    - 100,00-fold increase in light sensitivity in rods.

Electrical Activity of Retinal Cells

- Ganglion cells and amacrine cells are only neurons that produce AP.
- In dark, photoreceptors release inhibitory NT that hyperpolarizes bipolar neurons.
- Light inhibits release of inhibitory NT.
- Dark current:
- Rods and cones contain many Na^+ channels that are open in the dark.
- Causes slight membrane depolarization in dark.

Electrical Activity of Retinal Cells

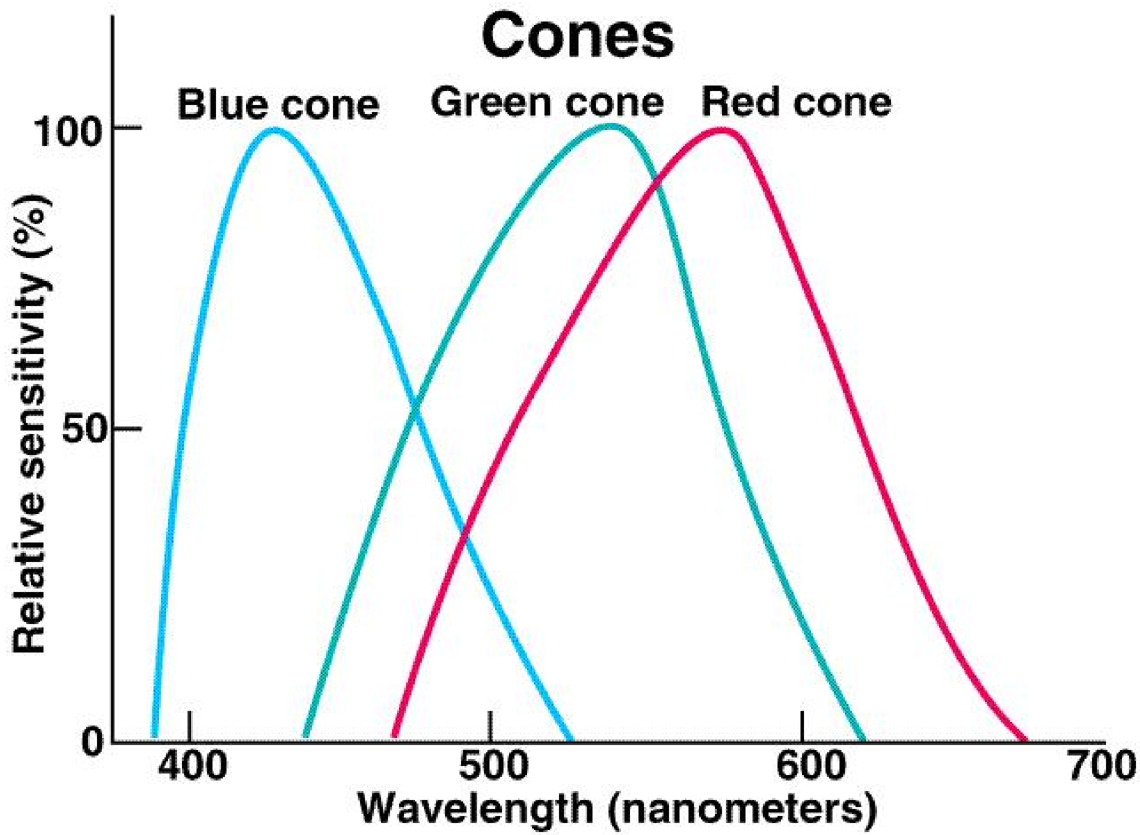
- Na^+ channels rapidly close in response to light.
  - cGMP required to keep the Na^+ channels open.
  - Opsin dissociation causes the alpha subunits of G-proteins to dissociate.
  - G-protein subunits bind and activate phosphodiesterase, converting cGMP to GMP.
  - Na^+ channels close when cGMP converted to GMP.

Cones and Color Vision

- Cones less sensitive than rods to light.
- Cones provide color vision and greater visual acuity.
- High light intensity bleaches out the rods, and color vision with high acuity produced by cones.

Cones and Color Vision

- Trichromatic theory of color vision:
  - 3 types of cones:
    - Blue, green and red.
    - According to the region of visual spectrum absorbed.

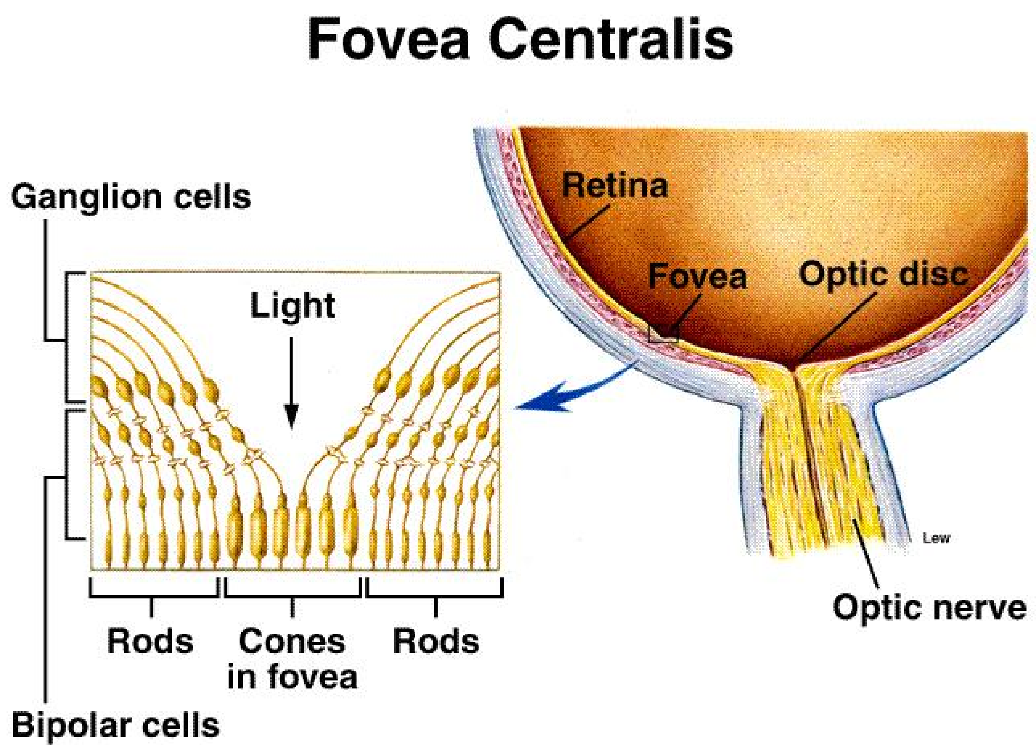


Cones and Color Vision

- Eachtype of cone contains retinene associated with photopsins.
  - Photopsin protein is unique for each of the 3 cone pigments.
- Each cone absorbs different wavelengths of light.

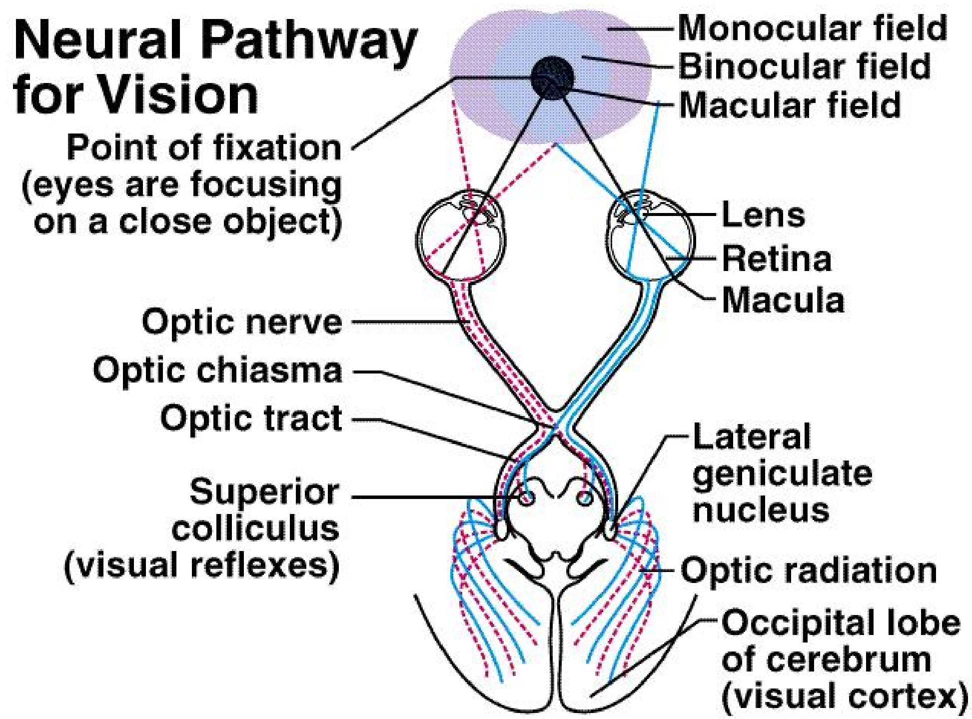
Visual Acuity and Sensitivity

- Each eye oriented so that image falls within fovea centralis.
  - Fovea only contains cones.
  - Degree of convergence of cones is 1:1.
- Peripheral regions contain both rods and cones.
  - Degree of convergence of rods is much lower.
- Visual acuity greatest and sensitivity lowest when light falls on fovea.



Neural Pathways from Retina

- Right half of visual field project to left half of retina of both eyes.
- Left half of visual field project to right half of retina of both eyes.
  - Left geniculate body receives input from both eyes from the right half of the visual field.
  - Right geniculate body receives input from both eyes from left half of visual field.
  - Neurons project to striate cortex.



Eye Movements

- Superior colliculus coordinate:
- Smooth pursuit movements:
  - Track moving objects.
  - Keep image focused on the fovea.
- Saccadic eye movements:
  - Quick jerky movements.
  - Occur when eyes appear still.
  - Move image to different photoreceptors.

Neural Processing of Visual Information

- Receptive field:
  - Part of visual field that affects activity of particular ganglion cell.
- On-center fields:
  - Responses produced by light in the center of visual fields.
- Off-center fields:
  - Responses inhibited by light in the center and stimulated by light in the surround.